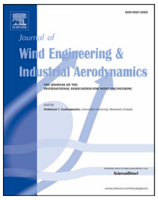
Journal of Wind Engineering & Industrial Aerodynamics 182 (2018) 1–15

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia



Numerical comparison of aerodynamic performance of stationary and moving trains with or without windbreak wall under crosswind

Jiqiang Niu [a], Dan Zhou [b], Yueming Wang [a,*]

[a] School of Mechanical Engineering, Southwest Jiaotong University, Chengdu, 610031, Sichuan, China
[b] School of Traffic and Transportation Engineering, Central South University, Changsha, 410075, Hunan, China

ARTICLE INFO

Keywords:
High-speed train
Aerodynamic characteristics
Windbreak wall
Crosswind
Moving train
Stationary train

ABSTRACT

The aerodynamic performance of stationary and moving CRH2c trains with or without a windbreak wall under crosswind was simulated by DDES based on the SST κ-ω turbulence model. In this paper we present a comparison between the pressure on and around the trains, velocity around the trains, and the forces experienced by trains. Our work is an attempt to understand the difference in the aerodynamic performance between stationary and moving trains with or without a windbreak wall under crosswind. In addition, our study aims to determine whether the method applicable to stationary trains could replace that for moving trains. The numerical algorithm used in this simulation is verified by comparing its results with those obtained in a wind tunnel test. The results show that for a train without a windbreak wall under crosswind, the method for stationary trains can replace that for moving trains to simulate the pressure field around and the aerodynamic forces of a train, although the results may be relatively conservative. Furthermore, the aerodynamic forces of the tail car are almost insensitive to the train motion; however, for the simulation of the velocity field around the train, replacement of the method for moving trains by that for stationary trains requires careful consideration. The results showed that, for a train with a windbreak wall under crosswind, the method for moving trains cannot be replaced by that for stationary trains because the new vortices that are produced close to the body of the train by the windbreak wall are significantly affected by the motion of the train.

1. Introduction

Researchers have been studying the aerodynamic performance of trains by using wind tunnels and dynamic model tests and numerical simulations with the view of improving the performance (Raghunathan et al., 2002; Cheli et al., 2010; Baker, 2010; Bell et al., 2014; Yang et al., 2016; Niu et al., 2017). The aerodynamic performance of a train deteriorates in the presence of crosswind, and performance analysis under crosswind has always been an attractive research topic. In a wind tunnel, the aerodynamic performance of a train under different wind conditions is usually simulated by changing the yaw angle (Bocciolone et al., 2008; Cheli et al., 2010, 2013; Schober et al., 2010; Niu et al., 2016). The method involving varying the yaw angle was also used in numerical calculations (Guilmineau and Chometon, 2009; Hemida and Krajnović, 2010; Krajnović et al., 2011; Cheli et al., 2012). Some researchers studied the aerodynamic performance of trains under crosswind by using moving vehicles (Krajnović et al., 2012; Basara, 2012). Although experimental analysis methods based on a moving train closely resemble actual situations, these methods are very expensive compared to numerical simulation methods that use a static train. In addition, only a few experimental devices are currently available to perform such experimental analyses. Lately, some researchers have begun to focus on the difference in the aerodynamic performance between static and moving trains under crosswind. An experimental device that can simulate the aerodynamic performance of a train under crosswind is being built at Central South University, China, but it has not yet been completed. In the UK, Dorigatti et al. (2015) studied the differences between model-based moving experiments and static experiments and found that, in terms of the overall mean aerodynamic side and lift forces and rolling moment coefficients, the static experiments are sufficiently accurate. However, the static experiments do not accurately represent the pressure distribution in the region around the nose of the train. Premoli et al. (2016) compared the aerodynamic performance of stationary and moving railway vehicles subject to crosswind with different yaw angles and found that when the stationary model is used, the lateral force and rolling moment coefficients are lower by approximately 5% and the vertical

---

[*] Corresponding author. Tel.: 086 15828136028.
E-mail address: ymwang@swjtu.edu.cn (Y. Wang).

https://doi.org/10.1016/j.jweia.2018.09.011
Received 26 July 2018; Accepted 10 September 2018

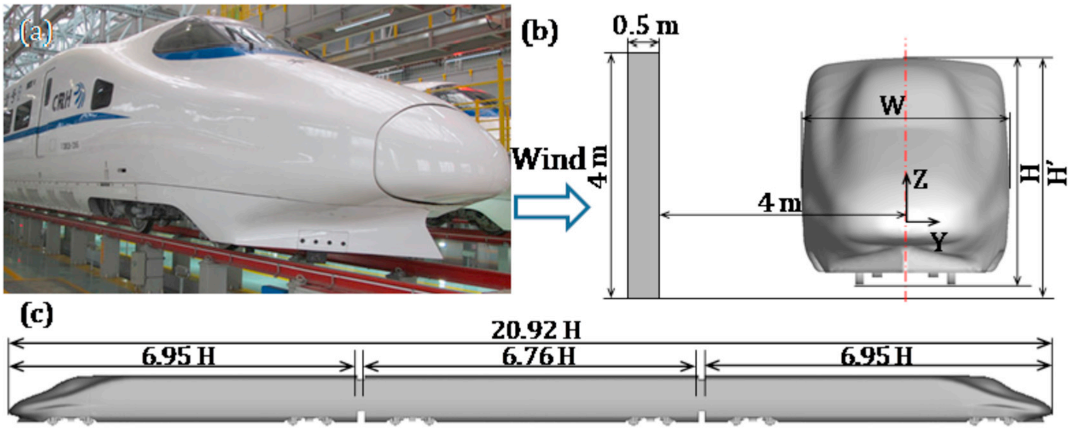


Fig. 1. Train model: (a) Full-scale version, (b) front view, and (c) side view.

force coefficient is lower by approximately 12%. Thus, although the static test is not conservative, some results still support its adoption as a representative test for train aerodynamics.

As is well known, a windbreak wall can effectively improve the aerodynamic performance of a train under strong crosswind (He et al., 2014; Zhao et al., 2015; Guo et al., 2015). However, as far as I know, there are no studies have focused on the comparison of the aerodynamic performance of stationary and moving trains with a windbreak wall under crosswind. It is unclear whether the method used for a stationary train is applicable to the simulation method for the aerodynamic performance of a train with a windbreak wall under crosswind, in terms of the extent to which these two methods differ from each other, or the causes for the differences between the two methods.

In this study, we simulated the flow structure around the train with or without a windbreak wall under crosswind by these two methods and analyzed the difference between them. The surface pressure and forces of the train were also compared and analyzed. The remainder of the paper is structured as follows. The geometric and mathematical models, including the train model, boundary conditions, grid generation procedures, and numerical methodology, are presented in Section 2. The algorithm validation is described in Section 3. The comparison of the aerodynamic performance of the stationary and moving trains with a windbreak wall under crosswind and associated analysis are presented in Section 4. Finally, the conclusions of the paper are listed in Section 5.

2. Numerical simulation

2.1. Geometric model

In this study, the CRH2c train (Fig. 1a) is used as the geometric model for numerical simulation (Fig. 1b and c). The train model used in both the wind tunnel test and numerical simulation is simplified according to the CEN European Standard (2008, 2009 and 2010). The train dimensions are shown in Fig. 1b and c. The length (L), width (W), and height (H) of a full-scale train model with two cars are 77.6, 3.38, and 3.7 m, respectively, the cross section of the train (*S*) is 11.2 m^2, and the distance between the roof of the train and the ground is H', which is 3.9 m.

2.2. Methodology

Large eddy simulation (LES) is an effective method for simulating the flow field, but its requirements for the grid around the train are computationally intensive and require extensive effort to be realized, especially in the region close to the train surface. In terms of the mesh density, the requirements of the Reynolds averaged Navier–Stokes (RANS) models are lower than those of LES, but it is difficult for RANS to accurately simulate the unsteady separation flows. Detached eddy simulation (DES) combines the advantages of the above two methods; that is, the flow field close to the train surface is simulated by RANS, and the flow field farther away from the train surface is calculated by LES. This combined method enables the number of grids around the train to be reduced significantly. However, DES has very strict requirements for grid generation. When the Reynolds number is very high, the improper grid refinement and improper location of the interface between RANS and LES would prevent the mesh density from supporting the Reynolds stress resolution of the LES in the exterior region of the boundary layer. Therefore, the switch caused a reduced eddy viscosity, an effect known as modeled stress depletion (MSD) (Spalart et al., 2006). Delayed detached eddy simulation (DDES) was therefore used in this study to prevent the occurrence of MSD and premature flow separation. The shear-stress transport (SST) κ–ω turbulence model was used to simulate the region close to the train surface since it has been demonstrated to be capable of reproducing a complex flow with large and adverse separations. Additionally, function f_2 in the SST κ–ω turbulent model was used to control the choice of numerical simulation methods. Therefore, DDES based on the SST κ–ω turbulent model was used to simulate the flow field around the train. Previous studies (Spalart, 2009; Hemida and Krajnović, 2010; Baker, 2010; Krajnović et al., 2012; Zhang et al., 2016) considered DDES to be effective for solving a fluid field with a large flow separation. In recent years, many researchers have used DDES to simulate the aerodynamic performance of trains and have achieved good results (Muld et al., 2012, 2014; Flynn et al., 2014; Morden et al., 2015).

In this study, the flow field around the train is simulated using Fluent, which is based on the finite volume method and a pressure-based solver, and the gradients are computed by applying the least-squares method to

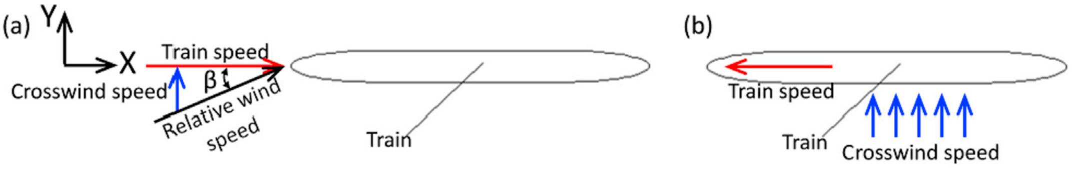


Fig. 2. Definition of the method for (a) stationary and (b) moving trains.