Journal of Wind Engineering & Industrial Aerodynamics 172 (2018) 395–408

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

# Comparative numerical analysis of the slipstream caused by single and double unit trains

Zi-Jian Guo, Tang-Hong Liu [*], Zheng-Wei Chen, Tai-Zhong Xie, Zhen-Hua Jiang

*Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha 410075, PR China*

ARTICLE INFO

*Keywords:*
Double unit train
Slipstream
Numerical simulation
DES
Open air

ABSTRACT

The use of double-unit trains is becoming a common means of increasing passenger capacity for a rail network. However, their expanded usage may create additional aerodynamic challenges. The present work obtains the characteristics of the slipstream caused by single and double unit trains using the detached eddy simulation (DES) method for 1/20th scaled models. The numerical results are verified by full-scale experiments. The slipstream velocities and pressures obtained by the two train models at different distances from the center of track (COT) and the top of rail (TOR) are compared. The coupling structure of the double-unit train model is found to produce a velocity peak that is much greater than that of the single-unit train model in the same position. At the area away from the COT and close to the TOR, the velocity of the far wake region is larger for the double-unit train model. The coupling structure also leads to a positive pressure change in the coupling region, and its value is comparable to or even much greater than that caused by the nose. It is considerable that the subsequent pressure criteria could take the positive pressure on the coupling region into account for the double-unit train.

## 1. Introduction

The movement of a train through the air generates velocity and pressure fluctuations, which in term generate forces acting on nearby persons, trackside workers, stationary objects, and track infrastructure. These forces can be of significant strength, and may damage trackside structures and destabilise nearby individuals (Flynn et al., 2016; Baker, 2010). Between 1972 and 2005, twenty four incidents involving flow-induced force acting mainly on wheeled items positioned on station platforms (e.g., pushchairs, wheelchairs, and trolleys), but also on passengers and their belongings, had been recorded in the UK (Flynn et al., 2014), and the incident rate was increasing somewhat (Baker et al., 2006).

The velocity of the slipstream generated by a moving train is dependent on the lateral distance from the COT, height from the TOR, and the speed of the train, as well as on the aerodynamic characteristics of the train, which are mainly affected by the geometric shape of the train (CEN, 2011). Previous studies have shown that the velocity of the slipstream is linearly proportional to the speed of the train (Soper et al., 2014). Different types of trains are employed for various transportation tasks, and the slipstream velocity and pressure changes caused by the moving train vary from type to type (Sterling et al., 2008; Herbst et al., 2012). For example, the normalized slipstream velocity of a Class 66 locomotive with 4 type B container wagons in tow calculated by Flynn et al. (2014) is much greater than that of a CRH2 high-speed train simulated by Huang et al. (2016), and the data onto both these train types differ from those of Intercity-Express (ICE) trains (Hemida and Krajnović, 2010). In fact, the flow fields around identical types of trains can differ owing to modifications in the shape parameters. For example, adjusting the streamlined length from 5 m to 15 m will reduce the trackside pressure peak-to-peak value by 47.0% and the maximum slipstream velocity by 34% at the respective locations required by the European standardization organization CEN (Chen et al., 2016). Moreover, the shape parameters, such as the slenderness ratio, roof-angle, height of the nose tip, and the rate of change in the cross-sectional area of the head car, are important determinants of slipstream characteristics (Bell et al., 2017; Zhang and Zhou, 2013). The geometric shape of other train components, such as the windshield, cowcatcher, and diversion slots and skirts, can also have significant impacts on slipstream characteristics (Yao et al., 2014; Krajnović, 2007). However, the aerodynamic performance optimization of high-speed trains is typically focused on the geometric parameters of the head and tail car (Liang and Shu, 2003; Zhu et al., 2016). The slipstream velocity and pressure changes caused by a moving train are also affected by the transport mode. For a freight train, the different container placement schemes vary the surface shape of the train, and thus affect the flow field around the train (Soper, 2016). Clear

---

[*] Corresponding author.
*E-mail address:* lth@csu.edu.cn (T.-H. Liu).

https://doi.org/10.1016/j.jweia.2017.11.022
Received 8 August 2017; Received in revised form 22 November 2017; Accepted 23 November 2017

differences in slipstream development have been observed for varying container loading percentages of 100%, 50%, and 33% (Soper et al., 2014). For passenger trains, the transport mode is mainly reflected in the marshalling schemes.

In China, trains including 8 cars are the usual transport mode, and few trains include 16 cars. However, the number of passengers has been steadily increasing, which requires further increases in the passenger capacities of high-speed railways. Increasing the transport frequency is an obviously poor solution owing to the inevitable increase in congestion and increased risk of accidents. Increasing passenger volume of conventional trains generally involves increasing the length of the train by adding additional intermediate cars. However, this represents a rather inflexible and inefficient means increasing passenger volume owing to the need to couple and decouple unpowered car units to meet the varying needs of passenger service. Alternatively, double-unit high-speed trains present an excellent means of efficiently increasing passenger capacity. Fig. 1 presents some examples of double-unit train that have been implemented in different countries. For double-unit trains, two shorter trains are connected by the two head cars to form a longer train. Double-unit trains are becoming increasingly implemented worldwide owing to their definite advantages. Firstly, double-unit trains provide for a very flexible passenger layout. Here, double-unit trains are employed during peak passenger volumes, and the train heads are uncoupled to function individually during low passenger volume periods. This not only accommodates different transport requirements, but also saves transportation costs by avoiding the need to couple and decouple unpowered car units. Secondly, the total number of seats in a conventional long train are less than that of a double-unit train. For instance, because the distribution of seat grades is different in 8-car and 16-car CRH380B, and the 16-car CRH380B has a complete dining car, thus a conventional CRH380B high-speed train with 16 passenger cars has a passenger capacity of 1,005, whereas that of a double-unit CRH380B high-speed train, where each unit has 8 passenger cars, is 1,112, which represents a 10.6% increase.

However, we note that the connection point of the two train units forms an inverted triangular groove structure in the coupling region (Fig. 1), which seriously affects the aerodynamic characteristics of a double-unit train. As a result, complex aerodynamic phenomena are likely to occur at high speeds. Therefore, the wider use of double-unit train requires that the resulting slipstream was considered in detail to protect the safety of individuals and the integrity of objects near the trackside, as well as for protecting track infrastructure. However, few studies regarding the slipstream phenomena of double-unit trains have been conducted. In past work regarding the aerodynamic performance of double-unit trains, Niu et al. (2017) investigated cases of a single moving double-unit train and two double-unit trains passing each other under both open air conditions and within a tunnel. It was determined that the coupling region had a marginal effect on the drag and lateral force under crosswind. However, the coupling region was found to increase fluctuations in the aerodynamic coefficients for each car under crosswind, but that the amplitude of the alternating pressure on the train or on the tunnel was significantly decreased by the coupling region. While the aerodynamic performance of each condition was explicitly analyzed, this study failed to consider the slipstream sufficiently. In this respect, experiments were conducted to obtain the characteristics of the slipstream around a double-unit train (Baker et al., 2013, 2014). These studies concluded that high-speed double-unit trains generate slipstream ensemble peaks just behind the junction and in the near wake of the train. Unfortunately, only the location of the largest slipstream velocity was recorded, and the complete characteristics of the slipstream around the train were not obtained. Therefore, to compensate for the deficiencies in past work, the present study focuses on changes in the slipstream velocity and pressure generated by the coupling structure of a double-unit train by comparing the slipstream and pressure around single and double unit trains. Comparisons are based on the characteristics of the slipstream caused by single and double unit trains obtained using the detached eddy simulation (DES) method for 1/20th scaled CRH2 models, and the numerical results are verified by full-scale experiments. The remainder of this work is organized as follows. The numerical simulation methodology is presented in Section 2 and the simulation results are presented in Section 3. Finally, Section 4 presents conclusions.

## 2. Numerical simulation

### 2.1. Model description

In order to meet the y + value requirements of DES, the single and double unit 1/20th-scale CRH2 models are employed in the present paper and of the same length. The models consist of six cars to meet the standards that the overall length of a train should be greater than 120 m and include at least a head car, two intermediate cars, and a tail car (CEN, 2011). As shown in Fig. 2, the single-unit CRH2 model is in a conventional marshalling scheme, where four intermediate cars reside between the head and tail cars. The first and last three cars of the double-unit CRH2 model are a head car, intermediate car, and tail car, and the two units are connected by a coupler. Both models include bogies and windshield sections, while the doors, windows, and handles are omitted. Except for the marshalling scheme, all other parameters, such as the cross-sectional area, bogie dimensions, and windshield dimensions, remain unchanged. For simplicity, the single-unit and double-unit train models are referred to as SUT and DUT models, respectively.

The height of each model $H = 0.185$ m (3.70 m for the full-scale dimension) is employed as the characteristic dimension; thus, the length of the head and tail car is given as 6.89H and that of the intermediate car is 6.76H, while the length and width of the overall model is 42H and 0.91H, respectively.

### 2.2. Numerical method

DES is a turbulence model originally proposed by Spalart et al. (1997). This model combines the advantages of Reynolds-averaged Navier-Stokes (RANS) and large eddy simulation (LES) approaches by utilizing RANS to approximate the mean boundary layer behavior and applying LES to capture the time-dependent flow at a distance from wall

**Fig. 1.** Double unit trains in different countries: (a) China; (b) Germany; (c) Japan.