J. Wind Eng. Ind. Aerodyn. 121 (2013) 39–48

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

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

Gusts caused by high-speed trains in confined spaces and tunnels

T. Gilbert*, C.J. Baker, A. Quinn

Birmingham Centre for Railway Research and Education, School of Civil Engineering, University of Birmingham, Birmingham, UK

ARTICLE INFO

Article history:
Received 4 January 2013
Received in revised form
31 May 2013
Accepted 26 July 2013

Keywords:
High speed trains
Air velocities
Slipstreams
Wakes
Gusts
Walls
Tunnels
Confined spaces

ABSTRACT

Little is known of the behaviour of transient air velocities and dynamic pressure loads generated by high-speed trains in confined spaces, or whether current methodologies for assessing transient gust loads in open spaces can be used in confined spaces. Experiments have been carried out in which a moving-model high-speed train passed walls, a partially-enclosed tunnel, and single-track tunnels with a variety of cross-sectional areas and lengths. An open air control experiment has also been carried out. The train model was a simplified 1/25 scale four-carriage ICE2 train travelling at 32 m/s. Cobra Probes measured the three-dimensional air velocity components at various positions inside the structures. The results show that the peak gust magnitudes increase in all confined cases compared to the open air. In tunnels, a 'piston effect' appears to have been a dominant cause of the increases in the peak gust magnitudes, as well as prolonged winds occurring before and after the train passed the probes. The tunnel length impacted considerably on the flow characteristics, and the partially-enclosed tunnel showed further increases in the gusts due to high lateral and vertical velocities.

1. Introduction

Passing trains impose transient slipstream gust loads on trackside workers and trackside furniture. Codes of practice require that the maximum gust load generated by a passing train is treated as a design load. Research by Sterling et al. (2008) into the fundamentals of transient slipstreams of high-speed trains found that the flow field in the open air can be defined by four regions, including: a nose region in which an inviscid velocity fluctuation occurs; a boundary layer region in which a turbulent and highly three-dimensional boundary layer develops along the length of the train on all sides; a near-wake region which is dominated by large-scale unsteady flow structures; and a far-wake region in which the slipstream velocity decays gradually. The relationship between the train's aerodynamic shape and the transient slipstream has been studied in Baker et al. (2013a), (2013b). The German Railways (DB) ICE2 train is the most widely and deeply researched high-speed train for transient aerodynamics, with many different assessment methods used, including: moving-model tests on straight tracks (Baker et al., 2001; Temple and Dalley, 2001), and rotating tracks (Del Valle, 2012); full-scale tests (Baker et al., 2013a, 2013b; Temple and Dalley, 2001); and CFD simulations, for example those which have used the 'simplified ICE2' or 'ATM' geometries (Krajnovic, 2009; Krajnovic et al., 2009; Hemida et al., 2012; Muld, 2012).

Until now, little attention has been devoted to assessing transient slipstream velocity gusts in 'confined spaces'. These include tunnels (defined as 20 m or longer by code of practice CEN (2006)), partially-enclosed tunnels which are slightly open to the atmosphere, and vertical surfaces running parallel to the tracks such as noise barriers, walls or deep cuttings. CEN (2003) provides a summary of the factors affecting slipstreams in tunnels – 'the induced flow velocity depends on the train speed, the blockage ratio [the train area divided by the tunnel area], the length of the train, and of the tunnel respectively, the roughnesses [sic] of the train and the tunnel wall respectively, and on the initial air speed in the tunnel'. It was stated that an upcoming code of practice would discuss the issues further. However this has not yet been fulfilled. A German national regulation (Deutsche Bahn, 2003) includes a relationship between the maximum air velocity in tunnels, the train speed, and the ratio of the cross-sectional areas of the train and tunnel, but its use may lead to over-predictions of air velocity, as was found in a comparison between prediction and experiment reported in Busslinger et al. (2009).

This investigation aims to establish how different configurations of confining infrastructure affect the transient slipstream velocities and maximum gust loads caused by a passing train. A parametric experimental study has been undertaken at the 'TRAIN Rig' moving-model facility in Derby (UK), which is owned

* Correspondence to: School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, West Midlands, B15 2TT, UK. Tel.: +44 7563791094.
E-mail addresses: tkg614@bham.ac.uk, timgilbert@hotmail.co.uk (T. Gilbert).

0167-6105/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jweia.2013.07.015

and operated by the University of Birmingham. The experiments involved firing a simplified ICE2 model train past various instrumented trackside structures. This paper compares the flow patterns and maximum velocities with various geometric parameters associated with the trackside structures. The methodology is described in Section 2. In Section 3, the reliability of the data is checked against results from previous studies and duplicated experiments and measurements. The data is presented and analysed in Sections 4 and 5.

2. Methodology

2.1. TRAIN Rig, simplified ICE2 model and test speed

The 'TRAIN Rig' moving-model facility consists of 150 m long tracks along which model vehicles can be propelled at speeds of up to 75 m/s. It is one of few aerodynamic facilities able to account for relative motion between vehicles, the ground, and complex structures such as train stations and tunnels. A simplified four-carriage 1/25 scale model ICE2 train was constructed, as shown in Fig. 1. The same train model and facility have been used in previous studies including Baker et al., (2001) and Temple and Dalley (2001), both of which provide datasets of open air transient slipstream measurements that are referred to in a comparison study in Section 3 of this paper. The former study also provides measurements of the model geometry. The test speed for this study was 32 m/s in order to match the test speed used in the former study for the benefit of the comparison study. The corresponding Reynolds number was 305,000 based on the speed and body height of the train (143 mm at 1/25 scale).

The reduced Reynolds number of these experiments means that some inaccuracy due to the scale effect is unavoidable. In a CFD study on train wakes, Muld (2012) compared the boundary layer momentum thickness along the tail carriage of the simplified ICE2 with that of full-scale trains. This parameter affects the points of separation of the flow around the train's tail, and hence the flow structures in the wake. It was found that the modelled four carriage train had a momentum thickness equivalent to a full-scale train with 12 carriages. This suggests that despite the relatively short length of this train and the low test Reynolds number, the wake flow structures are somewhat comparable to those occurring at full-scale in the open air. The data is compared with results from a previous full scale study in Section 3.

The speed of the model as it passed airflow measurement instruments was estimated from readings made by light gates stationed adjacently to the entrances and exits of the structures. 99% of the tested speeds were within 5.2% of the target speed of 32 m/s. The uncertainty of the train speed measurement is 0.71%, based on a comparison between manually calculated speeds from recorded light gate data with automatically calculated speeds.

2.2. Geometry and flow variables

Positions and lengths in this paper are normalised by the train height. x/Z, y/Z, and z/Z are the longitudinal, lateral, and vertical directions, relative to the direction of travel, with x originating from the tip of the train's nose, y from the track centre, and z from the railhead. The full-scale equivalent dimensions of the train are $X=105.4$ m (length), $Y=3.075$ m (width), and $Z=3.9$ m (height). The 1/25-scale dimensions of the train (as built) are $X=4.216$ m, $Y=0.123$ m, and $Z=0.156$ m. Some useful reference values are defined: The positions of the nose and tail of the train are $x/Z=0$ and 27 respectively; the distance of the side of the train from the track centre is $y/Z=0.39$; the height of the top of the train above the top of the rail is $z/Z=1$; the height of the top of the rail above the ground is $z/Z=0.077$; and the rail heads are approximately $y/Z=0.39$ apart (1.535 m at full-scale). The flow velocities in the longitudinal (u), lateral (v), and vertical (w) directions, and the resultant velocity (U), were converted into dimensionless coefficient forms with the train speed denoted by V. The dimensionless groups are as follows:

$$\left(\frac{x}{Z}\right)\ \left(\frac{y}{Z}\right)\ \left(\frac{z}{Z}\right)\ \left(\frac{u}{V}\right)\ \left(\frac{v}{V}\right)\ \left(\frac{w}{V}\right)\ \left(\frac{U}{V}\right)$$

where

$$\frac{U}{V}=\sqrt{\left(\frac{u}{V}\right)^2+\left(\frac{v}{V}\right)^2+\left(\frac{w}{V}\right)^2}$$

Two dimensionless variables are defined for the infrastructure. These are the blockage ratio β, which is the cross-sectional area of the train divided by that of the tunnel, and the leakage ratio, α, which is the ratio of the width of a gap in the cross-section of a tunnel divided by the total internal perimeter of a tunnel.

2.3. Test cases

Cross-section views and geometric details of the structures and instruments used in the tests are included in Fig. 2 and Table 1. The structures included a pair of walls (W1), single-track tunnels (T1, T1-B, T2, T3), and a partially-enclosed single-track tunnel (T2-P). Open air control experiments have also been carried out (OA). The standardised wall separation of $y/Z=0.84$ was chosen to allow a continuous walkway to theoretically run alongside the tracks, so worker access during train operation would be permitted for train speeds of 200 kph in the UK (RSSB, 2011) or 160 kph in Germany (EUK, 1999). The tunnel cases allowed the effect of changing tunnel length to be assessed, as well as α and β. The tunnel lengths were $x/Z=51$ (T1), 13 (T2), and 5 (T3), where $\beta=0.23$. The longest tunnel (T1) included a variation with a smaller cross-sectional area in which $\beta=0.3$ due to a lower ceiling height (T1-B). Tunnel T2 included a partially-enclosed variation (T2-P) in which $\alpha=4.3\%$, due to a slit running along the length of the ceiling. This particular α value represents the largest possible

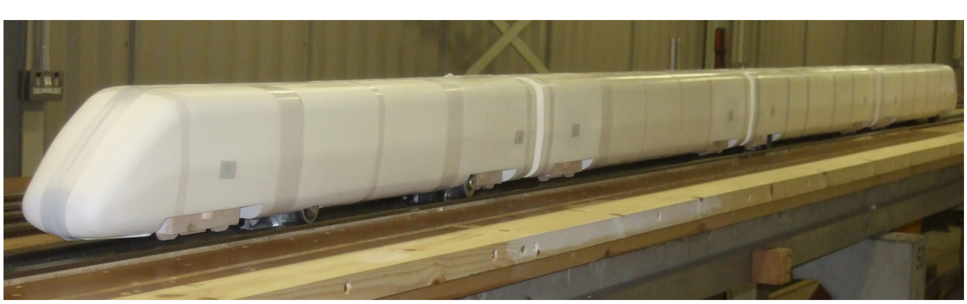

Fig. 1. Photograph of the simplified ICE2 model.