Journal of Wind Engineering & Industrial Aerodynamics 175 (2018) 111–119

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

High-speed freight trains for intermodal transportation: Wind tunnel study on the aerodynamic coefficients of container wagons

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ARTICLE INFO

Keywords:
Intermodal freight train
Cross wind
Container
Aerodynamic coefficients
Drag
Aerodynamic efficiency

ABSTRACT

The paper investigates the response to crosswind of a high-speed freight train for intermodal transportation, through wind tunnel tests. A 1:20 model of a freight train composed by an engine and two flat-car vehicles was instrumented with force balances to measure the aerodynamic coefficients of the flat-car plus container assembly and of the container alone. Aerodynamic coefficients strongly affects the train stability and the anchorage limits of the container itself.

During the wind tunnel tests, eight different loading configurations were considered and aerodynamic coefficients were determined for yaw angles (i.e. angle between train and wind) ranging from 0° to 90°. Experimental results show the benefits in terms of drag reduction due to the presence of a laden vehicle upstream. As far as the rollover risk is concerned, the less critical condition is found for a vehicle preceded by a fully laden wagon and followed by an empty one. More in particular, at low yaw angles, the worst condition for a vehicle occurs when the wagon ahead is empty while, for yaw angles between 45° and 55°, which are the most critical for 'low speed' trains, the differences with respect to the other configurations reduce significantly.

1. Introduction

The investigation of railway vehicles aerodynamics is of great importance both for economic and safety reasons; in fact, knowing the wind loads acting on a train-set allows, on the one hand, to address energy consumption issues and, on the other hand, to study the aerodynamic stability of the train. In this field, research has been mainly focused on passenger trains as they travel at higher speeds and are much lightweight with respect to freight trains (Baker et al., 2009; Baker, 2013; Cui et al., 2014; Dorigatti et al., 2015; Paradot et al., 2015; Premoli et al., 2016).

In recent years, environmental concerns and cost savings opportunities (at least for long-medium distances), increased the interest towards goods transportation by means of freight trains. However, simpler logistics management and door to door operation, still represent factors making road transportation strongly attractive. Increasing operating speed of freight trains appears as a way to improve the competitiveness of rail transportation overcoming part of its logistics limits.

In general, high speed poses a series of safety issues associated with the dynamics of the whole trainset and of the single vehicle (Cheli, Di Gialleonardo, Melzi). In the specific case of freight trains, due to the poor aerodynamic characteristics of the wagons, also crosswind may influence running stability even for speed below 200 km/h (Giappino et al., 2016). Moreover, intermodal freight trains carrying shipping containers, are characterised by wagons of various sizes, known as flatcars, well-cars and skeletonised cars. As a consequence, while in passenger trains wagons are in tight composition and the front section of a vehicle is not directly exposed to wind, in intermodal freight trains a significant gap between adjacent vehicles may be present. This variable loading configuration can have a strong impact on both the running safety, due to the overturning risk associated to cross wind but also the energy consumption and, thus, the transportation costs, especially when high-speed operation is required.

The necessity to operate goods trains at higher speed has thus given an impulse to the study of the aerodynamics of freight wagons with a particular focus on the optimization of the loading configuration of train used for intermodal transport.

Researches carried out in recent years are mainly focused on the analysis of aerodynamic efficiency, by using CFD analysis and wind tunnel tests. Considering the most recent ones, the evaluation of the aerodynamic drag coefficient with CFD analysis in Kedare et al. (2015) is performed for two different wagons geometries while in Östh and Krajnović (2014) allows to determine the effect of the boundary conditions. According to the study carried out by Östh and Krajnović, the drag

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https://doi.org/10.1016/j.jweia.2018.01.047
Received 26 October 2017; Received in revised form 29 January 2018; Accepted 30 January 2018

coefficient of the wagon when included in the train was found to be 90% lower than a wagon in free-stream. More recently, the effect on the drag of the wagon length and position in a train was numerically studied in Maleki et al. (2017), also accounting for upstream and downstream gap spacings. This last work is based on wind tunnel tests carried out with the same scope on reduced-scale wagon models as described in Li et al. (2017).

In alternative to CFD and wind tunnel analyses, semi-empirical formulations were proposed to predict the drag on a single vehicle in a given position along a train-set and to estimate the overall drag of a train (Lai et al., 2008b; Beagles and Fletcher, 2013). Evaluation of the efficiency of a load configuration and methods for its optimization are presented in Lai et al. (2008a).

Effects of aerodynamics on running safety did not receive the same attention, though the importance of this investigation was also remarked by the evidence of some crosswind accidents, which involved empty containers being blown away by the wind (Rail Accident Investigation Branch (RAIB), 2008). In Alam and Watkins (2007a) and Alam and Watkins (2007b), wind tunnel tests with a specific container wagon (double stacked) are performed to evaluated the aerodynamic coefficients as a function of the wind angles: the main limitation of these results is that they refer to a wagon in isolation, without accounting for the presence of the other wagons. Hemida and Baker (Hemida and Baker, 2010) evaluate the aerodynamic coefficients of a generic container wagon (single-stacked) using large-eddy simulation and accounting for the influences of the neighbouring wagons by imposing spanwise periodicity. The results are obtained for a crosswind at 90° yaw angle, with and without moving ground simulation. In Zhou et al. (2007), CFD analysis is used to compare, in terms of aerodynamic coefficients, different types of wagons while in Li and Tian (2012), the effect on the overturning risk due to cross wind of specific cross-loading structures positioned in correspondence of the gap between wagons, is studied by means of wind tunnel tests for double-deck vehicles. A more general study on the effect of the container loading efficiency and the presence of gap in front or behind a container on the aerodynamic coefficients is carried out in Soper et al. (2015), by means of moving model cross wind experiments conducted at the University of Birmingham's TRAIN rig facility. The tests, carried out at a yaw angle of 30° for three different consists, allowed to conclude that a reduced loading efficiency and, in particular, the presence of a gap in front of the container lead to an increasing on the aerodynamic forces and, as a consequence, to an higher overturning risk.

In this work, a more general analysis of the aerodynamics of a freight train for intermodal transportation was experimentally carried out by means of wind tunnel tests on steady models. A 1:20 model of a trainset made up of three vehicles (1 engine and 2 flat car wagons) was analysed considering eight different loading configurations and measuring the forces and moments generated by relative wind.

The main goal of this work is to evaluate the effects of different loading configurations at different yaw angles on the rollover moment coefficient, in order to find the best configuration minimizing the overturning risk associated to the cross wind. In particular, with respect to the results already presented in technical literature, in this work aerodynamic coefficients were identified for all yaw angles between wind and train-set ranging from 0° to 90°. In fact, as demonstrated in Giappino et al. (2016), due to the low operating speed, the range of critical yaw angle for lightweight railway vehicles for urban and suburban use, is between 40° and 55°. Critical yaw angles for high-speed trains are instead between 10° and 30°.

Moreover, the Characteristic Wind Curves of low-speed trains are generally more sensible to the wind direction than that of high-speed trains; for these reasons, in order to correctly evaluate the overturning risk of such a vehicles, it is important to analyse the whole distribution of the coefficients over the angles of attack. In addition, considering that the lateral wind is critical not only for the overturning risk but also for the anchorage of the container itself, the aerodynamic coefficients have been evaluated on both the whole of wagon (flat-car + container) and the only container. Finally, focusing the analysis on the drag coefficient with lateral wind, the effect of different configurations on the aerodynamic efficiency was evaluated.

In the next section the experimental wind tunnel setup and the tested configurations are described while in section 3 the results are shown and discussed.

The research activity presented in this paper is part of SIFEG project funded by the Italian Ministry of Economic Development (MISE). The project aims at increasing competitiveness of rail transportation by improving its logistic aspects and by designing high-speed container trains able to operate on high speed lines.

2. Wind tunnel tests

2.1. Test characteristics

Wind tunnel tests were performed on a 1:20 scale model of a freight train (Fig. 1). The convoy was tested in a flat-ground scenario (without ballast and rails), which is one of the reference scenarios described in the TSI 232/2008 standard European Rail Agency (2008).

The train model is composed by 3 vehicles: one front engine and two freight carriages instrumented to measure the aerodynamic forces.

The convoy composition was chosen in order on the basis of a trade-off between the minimum Re number required by the EN 14067-6 ($Re = 2.5\,10^5$) and the minimum number of vehicles necessary to correctly account for the boundary conditions to evaluate the crosswind performance of a railway vehicle (Baker et al., 2009; Baker, 2013). The selected solution complies with the requirements of the international standards (TSI 232/2008 and EN 14067-6) for the evaluation of the aerodynamic coefficients useful for the crosswind analysis, which is the main objective of the present paper. On the other hand, the authors are aware that the low number of vehicles penalises the correct evaluation of the drag coefficient, especially in terms of absolute value. In Golovanevskiy et al. (2012), the authors state, by means of numerical and wind tunnel experimental tests, that for long open cargo railway trains the model consisting of six rail cars with two streamlined bodies is the optimal configuration. Otherwise, from the presented results, it is possible to see that the main effects, due to different long compositions, are on the drag coefficient values and that the trend of this coefficient with the angle of attack is not influenced by the number of vehicles in the composition.

The wind tunnel is a closed circuit facility in vertical arrangement having two test sections, a 4×4 m^2 high speed low turbulence and a 14×4 m^2 low speed boundary layer test section. Tests were carried out in the High-Speed test section, whose characteristics are listed in Table 1. The test chamber is provided with a turntable (diameter 2.5 m) allowing to vary the yaw angle.

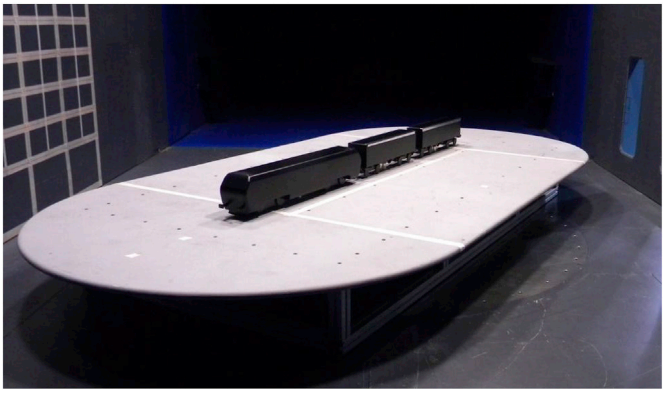

Fig. 1. 1:20 scaled model of the convoy in the High-Speed test section of the Politecnico di Milano Wind Tunnel.