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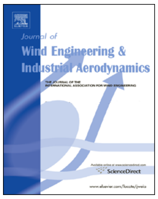

Cross wind and rollover risk on lightweight railway vehicles

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ABSTRACT

The paper investigates the effects of lateral wind on different type of railway vehicles, comparing the cross wind behaviour on a high speed train and on a modern train used for urban and suburban transportation. The second is characterized by a low operating speed, but also by a low mass that increases the overturning risk. In order to compare the two trains in terms of cross wind response, two subsequent analyses have been performed: measurement of the force aerodynamic coefficients by means of wind tunnel tests on scale models and evaluation of the rollover risk by means of the definition of the Characteristic Wind Curve through a simplified numerical procedure, based on the static equilibrium, proposed by the TSI standard (three mass model).

1. Introduction

One of the risks connected to running safety of high-speed trains is associated to overturning in strong cross winds (Baker, 1991a, 1991b; Baker et al., 2009). A great quantity of studies were performed over the last 20 years to understand the phenomenon and to develop methodologies able to evaluate the level of safety of a rail vehicle in terms of overturning risk.

First of all, the aerodynamic forces acting on the train have to be evaluated. The most common methods to define the aerodynamic coefficients are wind tunnel tests on reduced scale models (Cheli et al., 2013; Dorigatti et al., 2015; Kikuchi and Suzuki, 2015; Tomasini et al., 2014; Tomasini et al., 2015; Cheli et al., 2013; Dorigatti et al., 2015; Kikuchi and Suzuki, 2015; Tomasini et al., 2014; Tomasini et al., 2015; Schober et al., 2010; Suzuki et al., 2003) and CFD analysis (Cheli et al., 2010; Diedrichs, 2003). As a second step, the stability of the vehicle subjected to these forces has to be calculated: using the static approach, through a static equilibrium of the forces acting on the vehicle (Baker, 1991b , Imai et al., 2002, Bradbury et al., 2003, Tielke et al., 2008) or using a dynamic approach in the time domain (Tomasini and Cheli, 2013; Tielkes and Gautier, 2005; Xu and Ding, 2006; Ding et al., 2008; Baker, 2010), which allows to account for the non linear effects caused by vehicle dynamics and wind-train interaction. The final result of this procedure for the evaluation of the overturning risk is the definition of the Characteristic Wind Curve (CWC) which is the limit wind speed causing a vehicle to exceed safety limits such as, for example, wheel unloading (Cheli et al., 2012).

In Europe, within the framework of the Technical Specification for Interoperability (TSI, 2008) and in the European standard EN14067-6, the evaluation of the safety to cross wind is mandatory for high-speed trains. In particular within the TSI, trains are divided into 2 main classes: high speed trains (HS) having a maximum speed above or equal to 190 km/h and conventional trains running below 190 km/h. Additionally, the HS trains are divided into two groups: Class 1 for trains with speeds equal to 250 km/h and above and Class 2 for train speeds 190 km/h $\le \nu <$ 250 km/h. At present, methods and limits have been defined for TSI HS RST class 1 trains, while an "open point" is still present for TSI HS RST class 2 and for Conventional Rail Locomotives and Passenger Rolling Stock (CR LOC and PAS TSI RST has not been defined).

At national level, some European countries have established regulations for the analysis on crosswind stability; however, only UK, Germany and France (since 2013) have set rules into force for trains running below 250 km/h. The problem is complicated by the large differences in the infrastructure and train characteristics that is not present in HS trains.

All these standards (EN 14067-6, 2010, TSI HS RST, 2008 and national regulations) do not apply to the trains that run in urban or suburban areas for local transportation of passengers. The commercial top speeds of these vehicles is ranged between 80 and 120 km/h, but, even if cross-wind effects are of critical importance in high-speed trains, a deeper analysis of the lightweight railway vehicles shows that also these vehicles can suffer of these kind of problems because of their lightness and poor aerodynamic shape. Moreover, lightweight

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railway vehicles run often on circuits that get extra-urban areas and, as a consequence, the typical wind of these zones may rise very high values.

The goal of this paper is to compare the effects of cross wind on a low speed, light-weight train and on a high speed train, in the following named *LS* train and *HS* train. In order to compare the two trains in terms of response to cross wind, two subsequent analyses were performed: wind tunnel tests to measure the force aerodynamic coefficients and evaluation of the Characteristic Wind Curve (CWC) according to the procedure described in the standard TSI.

According to the European standard EN 14067-6 (2010) the cross wind stability of rolling stock is given by values of characteristic wind speeds that the rolling stock can withstand before exceeding some wheel unloading limit values. Various methods are available to determine the wheel unloading on passenger or freight vehicles due to cross wind. Sophisticated time-dependent multi-body simulation are often used to calculate the cross-wind stability (Tomasini and Cheli, 2013; Tielkes and Gautier, 2005; Xu and Ding, 2006; Ding et al., 2008; Baker, 2010), but also simpler methods are available, like the “quasi-static three mass model” that will be adopted for the present work.

2. Wind tunnels tests

2.1. Tests set-up

Wind tunnel tests on the two kinds of train were carried out in the Politecnico di Milano Wind Tunnel employing a 1:20 scale model for the LS train (Fig. 1a) and a 1:10 scale model for the HS train (Fig. 1b). LS train tests were performed in the high-speed test section (dimensions 4×4 m^2, maximum wind speed 55 m/s) in low turbulence flow conditions. The test section is characterized by an along-wind turbulence (I_u) below 0.1%, while the maximum mean velocity deviation across the section is less than 0.2%. The aerodynamic force coefficients for the HS train are available in EN 14067-6, 2010 (Table E.11: ETR 500 power car wind tunnel model). Table 1 resumes the main characteristics of the wind tunnel tests performed with the two investigated trains.

Table 2 summarizes the main dimensions (length, width and height) and the mass properties of the full scale vehicles for both the considered trains. Tests have been carried out on a true flat ground scenario (without ballast and rails), which is one of the reference scenarios described in the TSI 232/2008 standard (TSI HS RST, 2008). To realise the flat ground scenario a splitter plate, 350 mm high from wind tunnel floor, has been adopted in order to have an equivalent block profile of the mean wind speed.

A force balance (RUAG 192) is used to measure the overall forces and moments on the vehicles. The non-dimensional aerodynamic coefficients are defined according to the CEN standard. The reference frame system is fixed to the carbody and its origin is coincident with the carbody centre, at ground level.

The non-dimensional force coefficients are defined as follows:

$$C_{F_i}=\frac{F_i}{\frac{1}{2}\rho U^2 A_0}$$

$$C_{M_i}=\frac{M_i}{\frac{1}{2}\rho U^2 A_0 d_0} \tag{1}$$

where F_i (i=x,y,z) are the aerodynamic force components in the train's reference system and M_i (i=x,y,z) are the corresponding moments. In Eq. (1), ρ is the air density, U is the mean wind speed, d_0 is equal to 3 m (full scale), and A_0 is a standard reference surface which is equal to 10 m^2 (full scale).

The rolling moment is calculated both with respect to the middle of the track (CMx) and with respect to the lee rail (CMx lee). The sign convention of the yaw angle β between the relative wind-train speed v_a and the vehicle is shown in Fig. 2, where, in agreement with the EN 14067-1, 2003, the symbols have the following meaning:

- v_a: air speed relative to the train;

Table 1
Characteristics of the wind tunnel tests carried out with the two investigated trains.

Train	Model scale	Test section	Wind speed [m/s]	Reynolds number	Turbulence intensity [%]
LS: Low speed	1:20	High-speed	50	5 10^5	0.2
HS: High speed	1:10	Atmospheric boundary layer	14.5	2.9*10^5	2

Table 2
Dimensions and mass properties of the two investigated trains.

Train	Length [m]	Width [m]	Height [m]	Total mass [kg]	Lateral surface [m^2]	Centre of gravity height [m]
LS: Low speed	17.00	2.65	3.60	29,240	51.9	1680
HS: High speed	20.48	3.02	4.00	66,964	71.2	1329

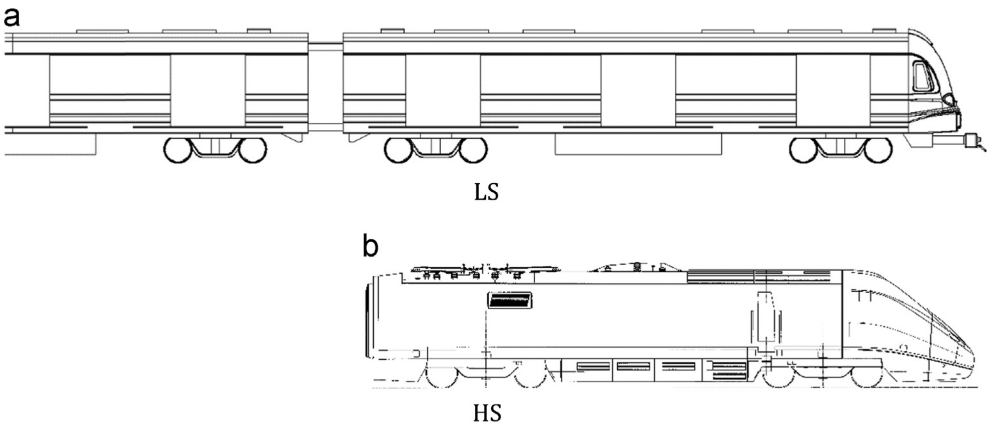

Fig. 1. Layout of the low speed train (a) and high-speed train (b).