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WIND TUNNEL TESTS ON TRAIN SCALE MODELS TO INVESTIGATE THE EFFECT OF INFRASTRUCTURE SCENARIO

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1 INTRODUCTION

A new European Standard on the cross wind theme for high speed trains is under edition within the “Technical Specification for Interoperability” (TSI, Ref. [4]): it defines a methodology to evaluate the safety threshold for a rail vehicle subjected to cross wind action, in terms of CWC (Characteristic Wind Curve). The CWC represents the limit wind speed that leads the vehicle to overcome specific safety limits. According to this methodology, the CWC (and, as a consequence, the train’s aerodynamic coefficients) have to be determined for two infrastructure scenarios: the flat ground and a 6m-high standard embankment.

At the present state, from the roll stock subsystem point of view, the TSI standard allows to consider a train interoperable if its CWC satisfies specific limit reference values. From the infrastructure subsystem point of view, the infrastructure manager is required to identify the most critical sites for a railway line. In order to develop a methodology to perform a risk analysis of cross wind on high speed lines, it is important to understand the effect of the infrastructure scenarios on the aerodynamic coefficients.

A typical railway line is characterized by two types of scenario: viaduct and embankment. In this work, the aerodynamic coefficients of the Italian high speed ETR500 train measured, through wind tunnel tests, for the standard TSI infrastructure scenarios (flat ground and 6m-high embankment) and for a typical Italian viaduct are presented and compared in order to understand the effects of infrastructure on aerodynamic loads.

2 WIND TUNNEL TESTS

Tests have been performed, with different scenarios, with two scale-models of ETR500 train:

- 1:10 scale model for tests on flat ground (with and without ballast and rails) and on the 6-m high standard embankment (Fig. 1) according to the geometry reported in the TSI (Ref. [4]);
- 1:20 scale model for tests with a typical Italian viaduct (Ref. [3]), 6 m-high at full scale (Fig. 2).

On the 1:10 scale models, an external 6-components industrial dynamometric balance was adopted for the measurement of the aerodynamic forces while, for the 1:20 scale models, the aerodynamic coefficients have been measured through an internal 6 components dynamometric balance, specifically designed for this application (Ref. [3]).

All the tests have been undertaken in smooth flow conditions (Ref. [3]), with different angles of attack, ranging from 0° (wind direction parallel to the train) to 90° (transversal wind).

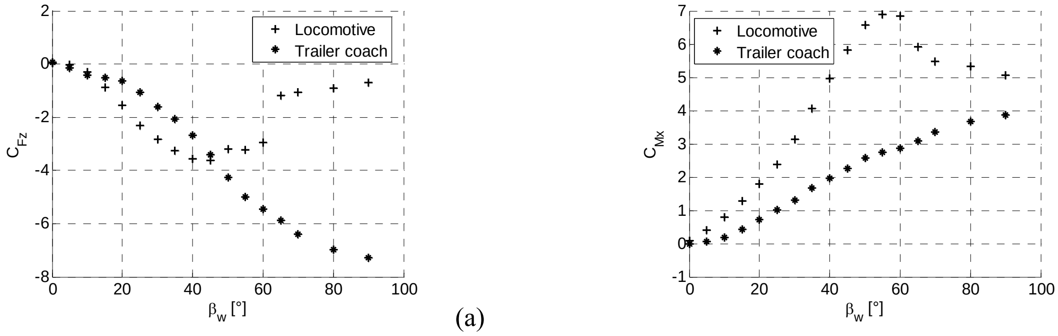
The reference frame adopted for the definition of the aerodynamic forces is fixed to the carbody and its origin is coincident with the carbody centre, at track level: x is the longitudinal axis, in the running direction, z is the vertical axis, upward directed, and y is perpendicular to define a right handed coordinate system.

Figure 1. Experimental wind tunnel tests: 1:10 scale model of ETR500 on embankment.

Figure 2. Experimental wind tunnel tests: 1:10 scale model of ETR500 on flat ground with ballast and rail.

3 AERODYNAMIC COEFFICIENTS OF THE ETR500 TRAIN

In this section, the aerodynamic coefficients measured on a 1:10 scale model of the ETR500 train are presented. Two infrastructure scenarios are considered, which are the same prescribed in the TSI standard: flat ground and 6m-high standard embankment. The results for both locomotive and first trailer coach are reported. Fig. 3 shows the most important coefficients for the cross wind analysis: the vertical force coefficient C_{Fz} and the roll moment coefficient C_{Mx}, referred to the TOR (defined according to the CEN standard, Ref. [4]). These coefficients have been measured on the 1:10 scale model of the power car and trailer coach of the ETR500 train on flat ground scenario (Fig. 3).

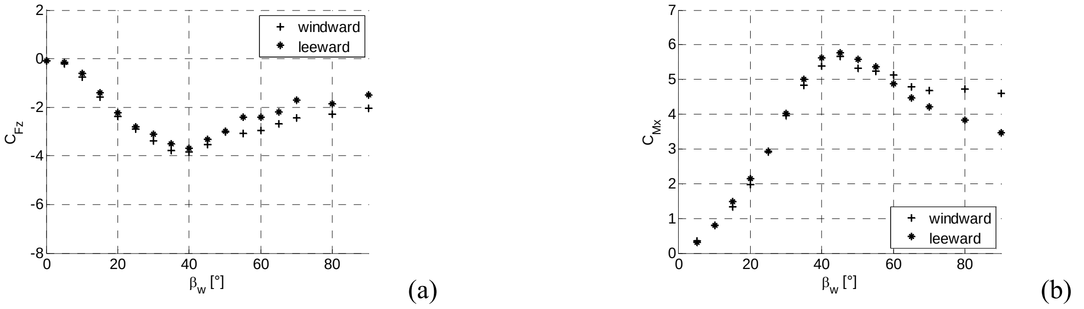


(a) (b)

Figure 3. ETR500, 1:10 scale model, flat ground: vertical force coefficients C_{Fz} (a) and roll moment coefficients C_{Mx} (b): locomotive vs first trailer coach (CEN conventions).

It is possible to observe that the first vehicle shows, for both coefficients, a maximum for angles between 45° and 50°, while the second vehicle reaches its maximum at 90°. The trend found for the locomotive is typical of all the leading vehicles of a convoy (Ref. [1], [2] and [3]) and it is due to a transition from slender to bluff body behaviour. Moreover, Fig. 3 shows also that the first vehicle is characterized by a roll moment coefficient higher than that of the second vehicle for all angles of attack; on the other hand, the values of the vertical force coefficient C_{Fz} of the power car are higher than those of the trailer coach only in the range 10°-45°.

The same coefficients, C_{Fz} and C_{Mx}, for the first vehicle of the ETR500 train on a 6m-high embankment are shown in Fig. 4, where a comparison between windward and leeward train's position is reported. It is possible to observe that the main differences between the two configurations arise, for both the coefficients, at high angles of attack, while at low angles, the C_{Fz} and the C_{Mx} seem not to be sensitive to the position of the train on the embankment.



(a) (b)

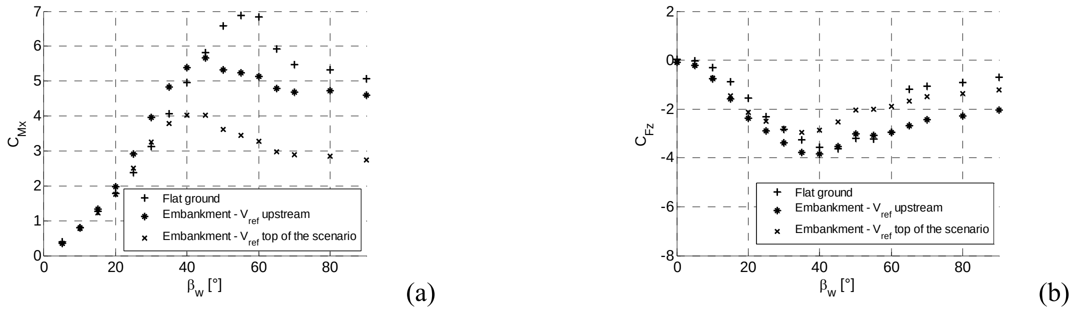
Figure 4. ETR500, 1:10 scale model, 6m high standard embankment, locomotive: vertical force coefficients C_{Fz} (a) and roll moment coefficients C_{Mx} (b) windward and leeward side (CEN conventions).

4 INFRASTRUCTURE SCENARIO EFFECTS

It is well known that the infrastructure's geometry influences the aerodynamic response of a rail vehicle (Ref. [2] and [3]). In the full paper, the aerodynamic coefficients measured with different infrastructure scenarios will be compared and the effect of the scenario on wind speed will be analysed. In particular, the 6m-high standard embankment and a typical railway viaduct will be taken into account and compared, in terms of coefficients, with the flat ground configuration, with and without ballast and rail. In this abstract, only the main results have been shown.

Fig. 5 shows respectively the vertical force coefficient C_{Fz} and the roll moment coefficient C_{Mx} measured on the 1:10 scale model of the locomotive of the ETR500 train, in terms of comparison between the 6m-high embankment scenario and the flat ground configuration without ballast. In particular, the aerodynamic coefficients measured with the embankment have been calculated by making reference to the incoming wind speed measured in two different positions: marker * refers to the coefficients evaluated for the wind speed of undisturbed flow (free stream, away from the embankment), while marker *x* corresponds to the coefficients calculated using the wind velocity measured over the embankment, without the train, in correspondence of the train position, 2m over the track. This second procedure is adopted to account for the speed up effect associated to the infrastructure scenario.

The data reported in Fig. 5 confirm the indisputable effect of the scenario on a train's aerodynamic behaviour. When considering the wind speed of the undisturbed flow as the reference one, the roll moment coefficient for train on embankment differs from that on flat ground, also for small angles of attack. In particular, the previous one is higher up to 40° and lower for higher angles of attack. If the roll moment coefficient for the embankment scenario is evaluated on the basis of the wind speed measured over the track, at low yaw angles (up to 35°), the coefficient itself is very close to the corresponding coefficient measured on flat ground. This demonstrates that, at low angles, the gap in the roll moment coefficient between flat ground and embankment can be substantially ascribed to the speed up effect associated with the geometry of the embankment. The practical outcome of this experimental result is that one can always use the flat ground coefficients, provided that the accelerated wind speed on top of the embankment is adopted as the reference one for the aerodynamic loads computation. Effective formulas are proposed in the literature to account for this speed up effect.



(a) (b)

Figure 5. ETR500 1:10 model, trailer coach: vertical force coefficients C_{Fz} (a) and roll moment coefficients C_{Mx} (b) on embankment, with reference speed upstream (+) and at the top of scenario (*), and on flat ground (x).

Looking again at Fig. 5, when considering large angles, the aerodynamic behaviour of the train is so influenced by the combined geometry of the complete system (train and embankment) that the physical phenomenon can not be simply reduced to a corrective coefficient related to the speed up effect, but the actual system geometry must be taken into account. In any case, it must be remembered that, when dealing with high speed trains, the train itself generally experiences wind angles smaller than 30°, also for limit wind speeds. As a consequence, the correction proposed for small angles of attack can be considered a useful mean to perform risk analysis calculations of specific embankment scenarios, starting from flat ground coefficients measured in wind tunnel. On the other hand, from Fig. 5 it possible to see that, up to 30°, the vertical force coefficient C_{Fz} measured on flat ground is lower than that measured on embankment, also considering the wind speed on the top of the scenario. It is the authors' opinion that, in this case, the gap between the two scenarios is due to the different boundary conditions in the underbody zone. In the full paper, it will be shown that the differences in C_{Fz} between flat ground and embankment scenarios are significantly reduced if the model of the flat ground scenario includes ballast and rail simulation.

Finally, in the full paper, wind tunnel test results for the other scenario typical of a high speed railway line, that is the viaduct, will be also presented.

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