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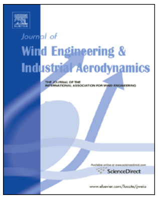

Experimental investigation of the effects of embankment scenario on railway vehicle aerodynamic coefficients

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ABSTRACT

The embankment is a typical layout for rail infrastructures, and train aerodynamic coefficients for the analysis of cross-wind effects with this scenario are required by the TSI standard. Nevertheless, wind tunnel tests on scale models with the embankment scenario present problems in the reproduction of the end layout conditions, that is the simulation of a "pseudo-infinite" full scale embankment. In this paper, the effect of different end layouts of the embankment model as well as wall proximity effects are analysed.

To study these two effects, two wind tunnel campaigns were carried out on a ETR500 train model 1:45 scaled. In the first tests, performed in a 1.5 × 1 m wide wind tunnel section, different embankment end layouts (wall-to-wall, finite length with and without noses, etc.) were reproduced and tests performed with different Reynolds numbers. The second experimental campaign was then carried out in a wider wind tunnel section (4 × 4 m), with a different distance between the end of the vehicle and the walls of the wind tunnel.

From the results of the first experimental campaign it was found that, in the 10°–40° range of wind angle, all the configurations with nose are generally equivalent, in terms of aerodynamic coefficients, to the wall-to-wall one, considered as the reference configuration (error range ±10%). Moreover, comparison of the results obtained with the different wind tunnel setups led to the conclusion that the distance from the upstream end of the ground model to the leading edge of the train model is a key parameter for determining aerodynamic coefficients with the embankment scenario, especially around the critical angle where the coefficients reach their maximum values. For this reason, this parameter has to be correctly reproduced to obtain coefficients comparable with full scale values.

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1. Introduction

The analysis of cross-wind effects on railway vehicles has become, with the development of new high-speed railway lines, one of the main problems in transport safety (Baker et al., 2009). The need for international interoperability standards has brought to the attention of the international scientific community the subject of cross-wind safety. Two international standards for railway vehicles issued in recent years EN 14067-6 (2010) and TSI HS RST (2008), have specific sections on cross-wind safety. The approach to evaluating the cross-wind stability of a railway vehicle described in these two standards, but also in a number of national standards, is based both on the determination of vehicle aerodynamic coefficients using (preferably) wind tunnel tests or CFD calculations, and on the evaluation of the maximum cross-wind speeds at which a vehicle reaches its safety limits, that is the Characteristic Wind Curves (Cheli et al., 2004, 2012; Carrarini, 2007; Sesma et al., 2012; Baker, 2010b; Ding et al., 2008; Diedrichs, 2003; Tomasini and Cheli, 2013).

In particular, in the TSI standard, wind tunnel tests are required for the evaluation of rail vehicle aerodynamic coefficients with two reference scenarios: flat ground and embankment. The flat ground corresponds to the condition of a train running on a flat terrain: this scenario is very simple to reproduce but is not realistic because it does not take into account the effects of infrastructure (ballast, viaduct, etc.) in the evaluation of the aerodynamic coefficients.

The embankment is a typical scenario for railway infrastructures: it represents one of the most critical scenarios owing to the flow acceleration associated with its specific geometry (Bocciolone et al., 2008; Cheli et al., 2010; Diedrichs et al., 2007; Peng and Xiaodong, 2010; Schober et al., 2010). Higher speeds at the top of the scenarios correspond to higher aerodynamic forces on the rail vehicle and, as a consequence, to greater safety risks.

In past years, wind tunnel tests have been carried out to study the topographical effects of the scenario (Baker, 1985) and to

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evaluate the effects of different embankment heights and boundary layer simulation on the flow acting on the train (Suzuki et al., 2003). Beside the experimental investigations using wind tunnel tests, in recent years CFD numerical analyses have also been carried out (Diedrichs et al., 2007; Ekeroth et al., 2009; Catanzaro et al., 2010).

Generally, the experience gained in these first experimental campaigns showed that the modelling of the embankment scenario in wind tunnel had some defects and open points (Cheli et al., 2010; Diedrichs et al., 2007; Suzuki et al., 2003):

- tests with still vehicle models, which do not reproduce the train-infrastructure relative velocity, do not permit correct simulation of the relative velocities train-wind (which should depend on vehicle speed) and infrastructure-wind (corresponding to the true wind speed, since the scenario is immobile also in real conditions);
- the model scale is limited by the need for a blockage ratio lower than 15% (EN 14067-6, 2010), or as lower as 10% (TSI HS RST, 2008) with a consequent reduction of the Reynolds number;
- the flow around the embankment simulated in the wind tunnel is significantly influenced by the unrealistic finite length of the scenario model and by the proximity of the wind tunnel walls, which modify the wind flow around the vehicle compared with real, open field conditions.

As concerns the first point, CFD numerical studies were performed to evaluate the effects of non-moving model tests on aerodynamic coefficients (Cheli et al., 2011c): these analyses showed that this effect, with the train set on the embankment infrastructure scenario, modifies of about 10% the lateral force and rolling moment coefficients, in the range of wind angle up to 30° (upwind and downwind) and of about 15% the vertical force coefficient. On the second point, the effects of the Reynolds number on vehicle aerodynamic coefficients have been studied by a number of researchers (Bocciolone et al., 2008; Cheli et al., 2011d; Baker, 1991) also comparing train coefficients measured in wind tunnel and on field at real scale (Baker et al., 2004); anyway, Reynolds number effects specifically with the embankment scenario are less studied (Schober et al., 2010). Finally, on the need to use noses at the ends of infrastructure models, tests have been conducted in Schober et al. (2010) and, for the viaduct, in Cheli et al. (2010). This paper deals with the analysis of the effects of embankment modelling on the evaluation of force and pressure aerodynamic coefficients of railway vehicles using wind tunnel tests on scale models. The aim of the research is to investigate different methods of performing wind tunnel tests with the embankment scenario and to propose a critical analysis of the TSI standard as regards the adequacy of the technical requirements it contains and, in general, the advisability of adopting the embankment as the reference scenario.

In particular, three main topics are analysed in this work:

1. the effects of Reynolds number in the range $[Re=4\times10^4 - Re=2.2\times10^5]$;
2. the effect of different embankment reproductions (with different end layouts);
3. the sensitivity of the coefficients to the distance of the vehicle model from the wind tunnel walls (wall proximity effects).

To study the three topics, two wind tunnel experimental campaigns were carried out with a 1:45 scale ETR500 train model on the 6 m-high embankment described in the TSI standard, with wind speeds from 10 to 52 m/s ($Re_{max}=2.2\times10^5$). In the first tests, performed in a 1.5 × 1 m wide wind tunnel section, two end layout conditions were simulated: a finite length embankment, with end-noses having different slopes, and a “pseudo-infinite” embankment, reproduced by wall-to-wall extension of the scenario. This is considered as the reference configuration because it represents the model most similar to the real infinite length embankment condition. Two different vehicle models were designed for the measurement of, respectively, aerodynamic forces and surface pressures. The final goal of this first campaign was to verify the minimum length of the embankment needed to obtain results equivalent, in terms of aerodynamic coefficients, to the ones found for the wall-to-wall configuration and to test different end-elements (noses) for the embankment.

The second experimental campaign was then performed in a wider wind tunnel section (4 × 4 m), with a greater distance between the vehicle ends and the wind tunnel walls. Moreover, in order to understand the effects of wall proximity, the results of the two experimental campaigns were compared with the reference data for the ETR500 train reported in EN 14067-6, obtained in a previous wind tunnel test carried out in the Boundary Layer Test Section of Politecnico di Milano (14 × 4 m wide) on a 1:10 scale model (Cheli et al., 2010). In particular, Section 2 focuses on the description of the wind tunnel experimental set-up while Section 3 describes the results of the two experimental campaigns.

2. Wind tunnel tests: Experimental set-up

All the tests described in this paper are compliant with the international standards (EN 14067-6, 2010; TSI HS RST, 2008).

Tests were carried out in two wind tunnels having different test section dimensions:

- A 1.5 × 1 m section of the Politecnico di Milano Aerospace Science and Technology department wind tunnel (hereafter named DIA section);
- A 4 × 4 m section of the Politecnico di Milano CIRIVE wind tunnel (hereafter CIRIVE1 section).

In addition, the force coefficients will also be compared with the reference coefficients for the ETR500 train reported in the EN 14067-6 standard (Table E.12). The tests to obtain these coefficients were performed in the Politecnico di Milano wind tunnel boundary layer test section (hereafter CIRIVE2) and are described in Cheli et al. (2010).

This data set was measured on a 1:10 scale ETR500 model positioned on a 6 m high standard embankment (Fig. 1). In this case the scenario had a fixed length of 130 m full scale (45° skewed end noses were adopted for yaw angles up to 20°, see Fig. 4) and the distance between power car and the test section wall was about 50 m full scale (at all yaw angles). At a 30° wind angle the blockage ratio was about 14%. All the three wind tunnels have a fully enclosed test section.

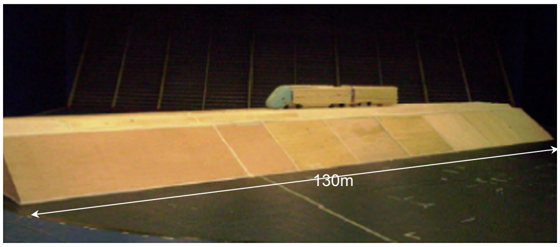

Fig. 1. CIRIVE2, boundary layer test section (model scale 1:10).

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