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WIND TUNNEL INVESTIGATION OF AN ICE 3 ON AN EMBANKMENT

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1 Introduction

The aerodynamics of a train under the influence of cross winds is a safety relevant topic which is covered in European legislation within the framework of the Technical Specification for Interoperability (TSI).

The modeling of cross wind acting on a train inside a wind tunnel represents a challenge due to the differing ground scenarios, e.g. flat ground corresponding to the situation on bridges, ballast and rail corresponding to regular tracks as well as the special case of high embankments. The modeling is especially complicated due to the differing relative speeds and yaw angles between the wind and the train on the one side and the wind and the ground on the other side.

In addition to the ground modeling difficulties, the Reynolds number of modern high speed trains based on train width and a cruising speed of 350 km/h is approximately Re = 2×10^7 and imposes a further challenge for most conventional wind tunnels.

The present study investigates the influence of three stationary ground configurations on the aerodynamic coefficients of a modern high-speed train.

2 Experimental setup

A scale 1:15 model of an ICE 3 has been investigated in the Audi aero-acoustic wind tunnel. The ground configurations on which the ICE 3 was investigated are shown in figure(1):

- A **Flat ground** configuration with a gap of 235 mm (Full scale) between the wheels and the ground (According to TSI)

- A **Ballast and rail** configuration with a height of 1m (Full scale) (According to the recommendation of prEN14067 part 6)
- An **Embankment** configuration with a total height of 6m featuring double track ballast and rails (according to TSI)

a) b) c)

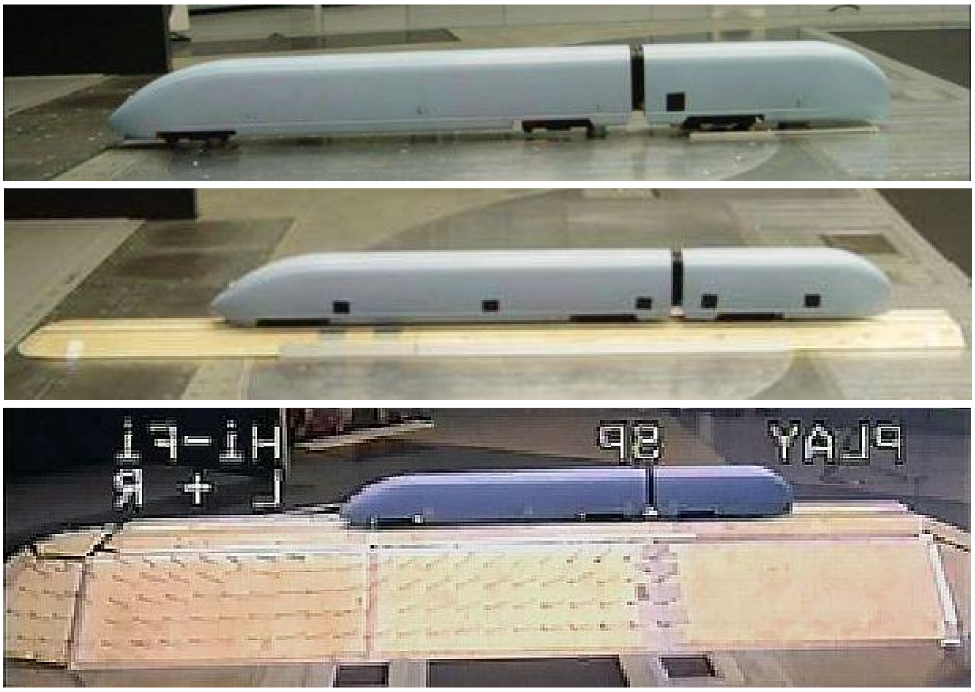

Figure 1: ICE 3 on a) Flat Ground, b) Ballast & rail, c) 6 m Embankment

3 Results

3.1 Tuft visualization on an embankment

Figure 1c shows a tuft visualization on the embankment at a yaw angle of 40°. As can be seen, the flow field on the leeward side is strongly three dimensional and directed upwards showing the footprint of a longitudinal vortex.

A change of flow direction near the leading edge of the embankment is clearly visible, highlighting the effect of the presence of the embankments nose shape. [1]

3.2 Force coefficients

The force and moment coefficients of the ICE 3 are shown in figure 2. In addition to the directly measured aerodynamic properties on flat ground (FG), ballast and rail (Ballast) and the 6m high embankment (Embankm), calculated coefficients for the embankment case using the Baker hypothesis based on flat ground (FG-Baker) and ballast an rail (B&R-Baker) are shown. The most important parameter with respect to cross-wind stability is c_{mxlee}, which is shown in figure 2. It can be noted, that the flat ground results are considerably below those obtained on

[1] This effect can be minimized by extending the embankment further upstream up to the nozzle exit, however, at the cost of inference problems between wind tunnel nozzle and embankment.

the ballast and rail configuration. The measured coefficients on the 6m embankment are above the ballast and rail results for yaw angles below 40°, but drop significantly below those of ballast and rail for angles above 40°.

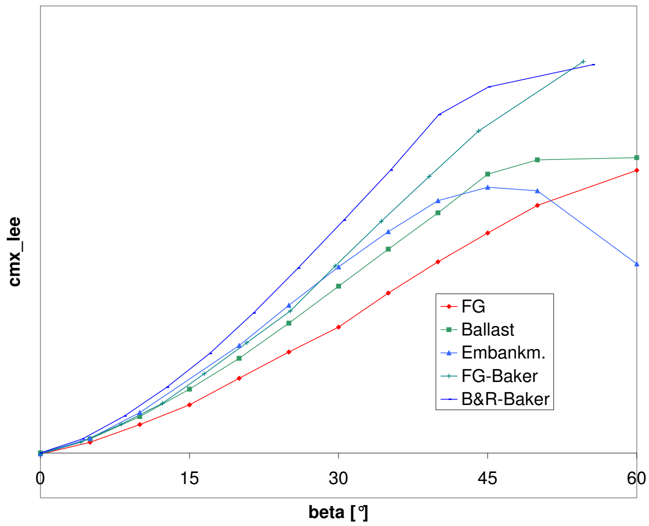

Figure 2: Roll moment coefficient about leeward rail of an ICE 3 on different ground configurations

3.3 Comparison with Baker hypothesis

When applying the Baker hypothesis to the measured flat ground and ballast and rail coefficients in order to generate coefficients for the 6m embankment, it becomes apparent that the coefficients obtained through the Baker hypothesis are larger than those measured directly on the embankment. This is attributed to the fact, that the flow around the embankment in the wind tunnel experiment significantly differs from the full scale case, since in the full scale case, the most critical case with respect to the train is associated with wind approaching the embankment from a nearly perpendicular direction whereas during the wind tunnel experiment the embankment is approached under approximately the same yaw angle as the train.

4 Discussion

4.1 The flow of wind over a skewed obstacle

A generic embankment, as it has been used in wind tunnel studies, has many similar features to "generic flow configurations", such as the backward-facing step or the fence, where a variety of publications exist. For example, Fernholz et al. [1] showed, that the flow behind a skewed backward facing step (cf. figure 3) shows 3 regions that depend on the skewing angle.

- A "quasi 2-dimensional" separation for skew angles of 0^o to approximately 30^o. Here, the independence principle of Prandtl is valid. Flow features as for instance the separation length, scale with the velocity component normal to the step.

- A "quasi 2-dimensional" separation for skew angles of 50^o to approximately 90^o, which is dominated by a strong longitudinal vortex immediately behind the step. Flow features as the separation length are dominated by the velocity component parallel to the step.

- A "strongly 3-dimensional" separation for skew angles of 30^o to approximately 50^o, where a transition between the above two patterns takes place, i.e. the flow field depends on both step normal- and parallel component.

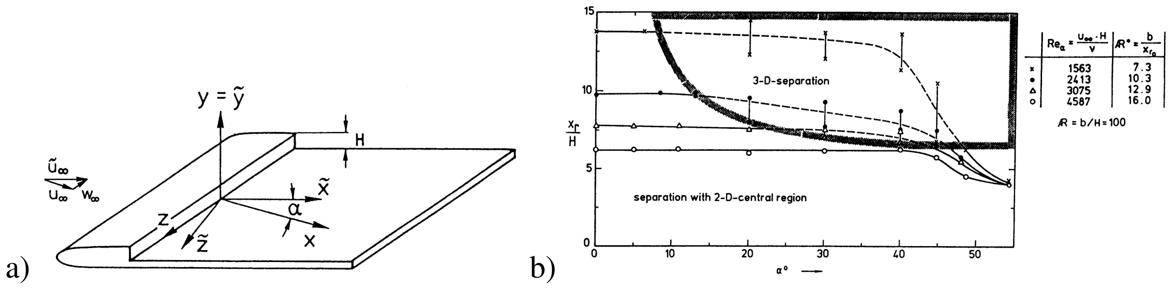

Figure 3: The flow around a swept backward facing step

Orellano et al. [2] showed, that for modern high speed trains the wheel unloading due to cross wind is strongest for yaw angles of 10^o to 30^o. Due due to the large velocity of the train ($v_{train} \approx 100$m/s) relative to the ground, this corresponds to nearly perpendicular wind relative to the track (80^o to 90^o) with a wind speed of approximately 30 m/s. We therefore can conclude, that for the real operation of a train, the characteristic velocity corresponds to the train speed and the dominant flow feature is the longitudinal vortex generated on the leeward side of the train. For the real flow across an embankment, in contrast, the characteristic velocity is the wind velocity, the angle of attack is nearly perpendicular and the flow is quasi two-dimensional.

Within a wind-tunnel experiment with stationary embankment, the embankment is subject to nearly the same angle of attack and flow speed as the train and therefore, is also subject to a strong longitudinal vortex (see figure1c) that is not present under real operational conditions. A separation of the velocity into components normal- and parallel to the embankment (Prandtl's decomposition) is not possible in the yaw angle range under consideration.

5 Conclusion

An ICE 3 model has been investigated in an automotive wind tunnel on three different ground configurations. The aerodynamic force and moment coefficients reveal a strong dependency on the ground configuration, with the embankment configuration giving the highest measured coefficients. When applying Bakers hypothesis to the flat ground and ballast and rail data in order to compute the corresponding coefficients for the 6m embankment, only poor agreement could be found. This is contributed to the fact that during the wind tunnel investigation with an embankment a strong longitudinal vortex is generated on the leeward side of the embankment that does not exist in reality and significantly alters the overall flow field.

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