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The Effect of Boundary Layer Control with Roughness Elements on the Wake Flow of Moving Train Models

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Abstract: Moving model experiments are used to investigate the flow around three different train geometries. Due to the difference in the Reynolds number, the flow might not be directly comparable to full-scale measurements. Boundary layer control is used to influence the flow around the train model and increase the boundary layer velocity. With view on the standards given by the Technical specification of Interoperability, the analysis of the wake shows increased maximum induced flow velocities at the specific standard measurement position.

Keywords: slipstream, boundary layer control, wake flow structure, TSI, moving train model, high-speed particle image velocimetry, tunnel simulation facility

1 Problem Statement

Moving model experiments at the tunnel simulation facility Göttingen (TSG) allow a transient measurement of the flow velocity induced by a passing train model scaled 1:25 under realistic motion conditions between train model and ground. The aim of model experiments is to investigate new model geometries with less time and cost consumption compared to full-scale tests. The induced flow velocity at a specific measurement position is one of the critical values for approval given by the Technical Specifications of Interoperability (TSI, [1]). Previous measurements have shown that the maximum flow velocity of a passing high-speed passenger train occurs in the near wake. The main objective is to study the flow comparability between moving model experiments at the TSG and full-scale tests to predict limited values like the maximum induced flow velocities for new train geometries. Due to the scaling of the train model and the limitation of the model length by the TSG setup, the Reynolds number is lower than in full-scale and the flow might not be directly comparable. It is assumed, that the profile and thickness of the boundary layer at the rear end are important for the wake structure development. The flow around the rear end shape forms to the near wake flow, which dynamics are crucial for the maximum induced flow velocity at the TSI respective measurement position. Because of the limited model length, the boundary layer thickness at the rear end of the train model is expected to be too small as shown in [2]. The idea is to increase the boundary layer thickness using vortex generators at the model head section. A more detailed description of the so called roughness elements can be found in [3] and [4]. Previous investigations have shown that the roughness elements lead to an increase of the flow velocities within the boundary layer. The scope of this work is to determine the effect of the roughness elements on the wake flow and the maximum induced flow velocity respective to the TSI. It hast to be noted, that the TSI value $\mathrm{U}_{2\sigma}$ is calculated as the sum of the mean maximum velocity $\overline{\mathrm{U}}$ and the doubled standard deviation 2σ of multiple train passes (cf. [1]). Therefore, the wake analysis considers the effect of the roughness elements on the TSI value as well as the separate effect on the mean maximum flow velocity and the effect on the standard deviation. Within the scope of this work, three measurement series with different train models are compared. The induced flow velocity of the train models has been measured with High-Speed Particle Image Velocimetry (HS-PIV) at the tunnel simulation facility Göttingen (TSG). Further details of the measurement technique and setup can be found in [2], [3] and [4]. A short overview of the HS-PIV setup at the TSG is shown in Fig.1a. The flow velocity is measured within a plane parallel to the ground at the TSI respective scaled measurement height of 8mm above the top of rail (TOR8, cf. Fig.1b).

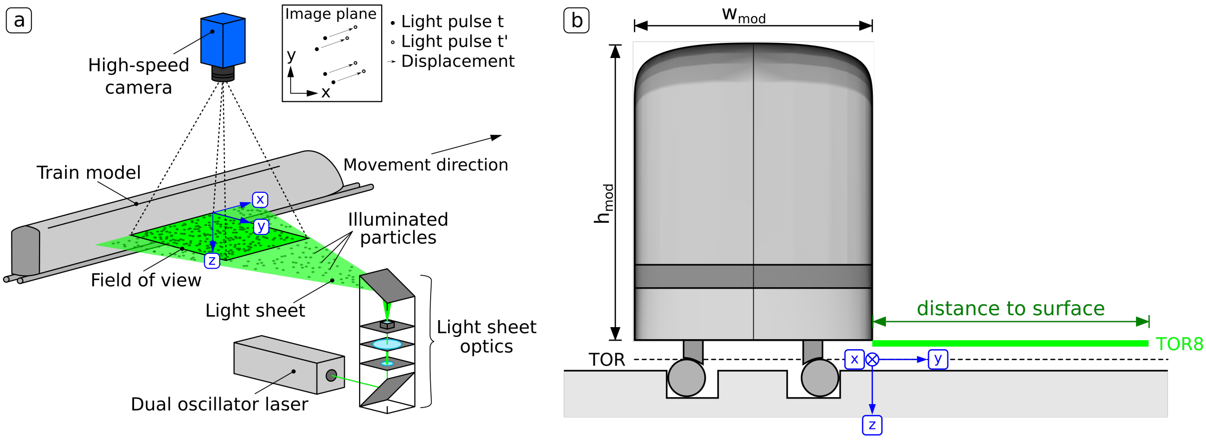

Figure 1: Measurement technique of High-Speed Particle Image Velocimetry (a) and the setup at the tunnel-simulation facility with view on the rear end of the train model (b).

Figure 2: Train Models with a generic head shape in a smooth and rough surface configuration (left). The coaches have a simplified geometry of a double-deck train, an ICE3 and a generic train (right).

The three different train models are shown in Fig.2. The total train model length varies between 2.1m and 2.3m. Each train model has a generic head section to remove specific effects of the different head shapes on the boundary layer. The head section can be modified from a smooth surface to a rough surface by attaching roughness elements. The middle and end coach of the model have a specific train geometry scaled 1:25. The first measurements were performed with a simplified double-deck train model (DD, see [3]) with a short end section compared to the height and width. The induced flow velocities were measured at TOR8 with a smooth (CLN) and a rough surface (RGH). The second measurements were performed with an ICE3 train model (see [4]). The end section is significantly longer with a smaller radius of curvature. As part of these measurements, the effect of three different shaped roughness elements (RGH1/2/3) with increasing size are compared to a clean surface (CLN). The third measurements were performed with a generic train model similar to an ÖBB-Railjet geometry (see [2]), which has in the clean configuration a total smooth surface without inter-car gaps or open bogie sections. The induced flow velocity is measured with a smooth surface (CLN) and a rough surface (RGH) as well as an optional inter-car gap (GAP) between the middle and end coach. 10 test runs per configuration were performed with the double-deck model and 30 test runs per configuration with the ICE3 and the generic train. The model speed is set to u_{mod}=32m/s.

2 Results and discussion

With view on the TSI, the maximum flow velocity $U_{max}(x)$ was determined at a distance of 0.12m to the track center for each grid point in x within the PIV images. The considered grid points in x might contain redundant information, but improve the statistics. The mean maximum flow velocity $\overline{U}$ and the standard deviation σ were calculated including $U_{max}(x)$ of all runs for each configuration. The flow velocity was normalised with the model speed.
Conditional sampling was used to extract the flow structure at the time of maximum induced flow velocity. Therefore, the middle grid point x_{mid} at the TSI distance was considered as reference point. For each run, the flow field at the time t^* of maximum velocity $U_{max}(x_{mid})$ was determined. Fig. 3 shows 6 selected flow fields next to the model surface (y=0mm) respective to the maximum condition: (a-c) generic train, smooth surface, (d-f) generic train, rough surface. The maximum flow velocity varies between $0.2<U_{max}<1$. The comparison of the flow fields suggests different kinds of flow structure, which correlate to the magnitude of the flow velocities within. In case of relative low $U_{max}(x_{mid})$, the flow field shows a large structure with a mostly homogeneous distribution of low velocities. For relative high $U_{max}(x_{mid})$, the flow structure is smaller with higher dynamics and velocity gradients. It is notable, that the comparison between smooth and rough model surface shows an increase of the flow velocity magnitude for similar shaped flow structures. This agrees with the results of the mean flow structures calculated with the same method for the double-deck train model shown in [3]. The scope of further analysis will be an investigation of a wake flow topology (cf. [5]).

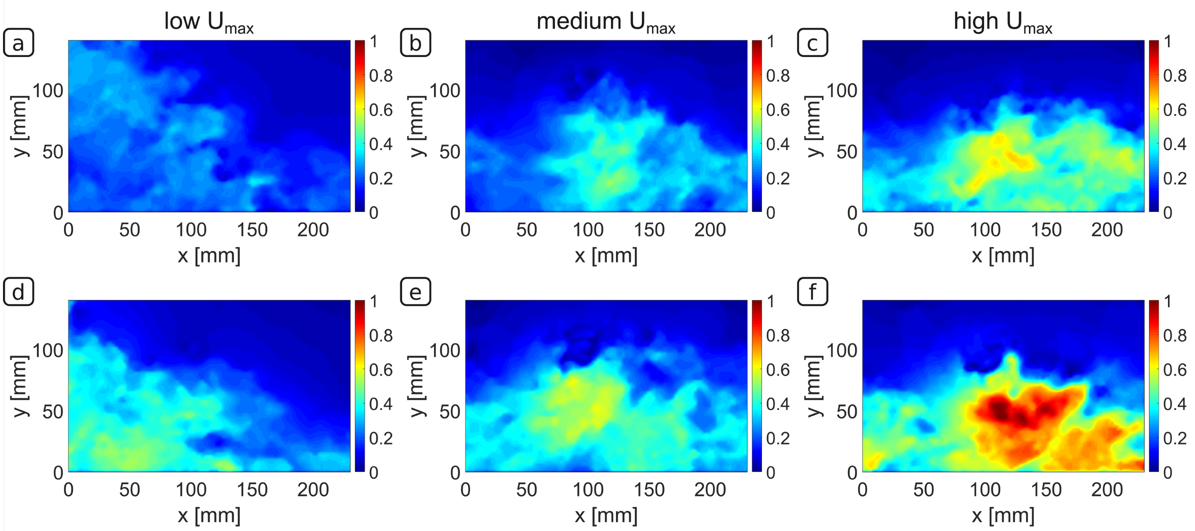

Figure 3: Selected flow structures at the time of maximum flow velocity U_{max} at the reference position x_{mid} for a generic train with a smooth surface (a-c) and a roughness surface (d-f).

The comparison of the calculated mean value $\overline{U}$ and standard deviation σ as well as the resulting $U_{2\sigma}$ is shown in Fig.4. The percentage increase by the use of roughness elements compared to a smooth surface is shown above the bars. It should be noted, that in contrast to the TSI no moving average filter is used and $U_{2\sigma}$ is not directly comparable to the TSI values. Fig.4a shows that $\overline{U}$ is increased by the use of roughness elements compared to a smooth surface for all train models. Furthermore, $\overline{U}$ is also increased for the inter-car gap configuration with the generic train model. The inter-car gap seems to affect the wake flow similar to a roughness element. The comparison of the standard deviation σ shown in Fig.4b indicates that the effect of the roughness depends on the train model. While σ is almost unaffected in case of the double-deck model, σ is decreased in case of the ICE3 with roughness compared to a smooth surface and increased in case of the generic train with roughness or an inter-car gap compared to a smooth surface. This is an important observation since the standard deviation is considered twice in the calculation of $U_{2\sigma}$ shown in Fig.4c.

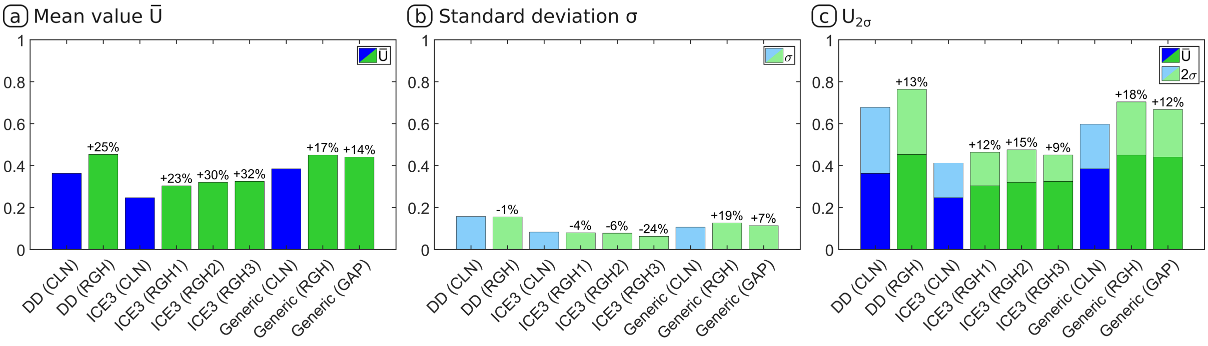

Figure 4: Comparison of the mean value $\overline{U}$ (a), the standard deviation σ (b) and the resulting $U_{2\sigma}$ (c) for the three different train models with configurations at TOR8.

The results show, that boundary layer control with use of roughness elements and the increased boundary layer velocities lead to an increase of $U_{2\sigma}$ for all three train models. The main effect corresponds to the increased mean value $\overline{U}$, while the different effect on the standard deviation σ can reduce or increase $U_{2\sigma}$ depending on the train model or rear end shape. In further analysis the correlation between roughness effect on the fluctuation in the boundary layer and the standard deviation in the wake flow will be investigated. Additionally, including ICE3 full-scale data, the ratio between the mean value velocity $\overline{U}$ and standard deviation σ will be verified. Furthermore, it can be checked, if the roughness elements improve the comparability between model experiments and full-scale measurements with respect to the TSI values.

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