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A GENERIC TRAIN-UNDERFLOOR EXPERIMENT FOR CFD VALIDATION

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1 INTRODUCTION

The investigation of the underfloor flow field of high-speed trains is motivated by several aspects which affect system security and performance: cruising speeds are approaching values where ballast projection becomes a serious issue, requiring the optimization of the underbelly design in order to reduce the aerodynamic load on the track bed. With the increase in energy cost the reduction of the drag by use of bogie fairings becomes attractive as well as for noise reduction purposes. Since both full-scale tests and wind-tunnel tests over moving belts or with moving model rigs are costly the interest in CFD as a tool for the flow assessment and investigation of the effects of design changes has increased.

Commercial solvers have reached a state where technical issues such as meshing for complex geometries, convergence rate, memory requirements and computational resources can be handled. Nevertheless, the flow region in the gap between the underbelly of the vehicle and the trackbed poses a challenge to turbulence modeling since the highly-turbulent non-equilibrium flow is characterized by features which have shown to be difficult to capture within the classical steady RANS approach: the Couette type flow is regularly interrupted by the passing bogies and the cross-sectional changes at the inter-car connections. It is characterized by flow separation and formation of vortices at sharp edges and behind bluff bodied geometry details, by large-scale unsteadiness, and by intense secondary flow [1].

Thus, it is necessary to validate turbulence modeling approaches by comparison of flow field predictions with measurements either from the track or from the laboratory. Within the research cooperation “Aerodynamics in Open Air” the four partners DB AG, Bombardier, Siemens AG and CAF dedicated resources for the design and the realization of a laboratory investigation of a generic underfloor geometry in scale 1:7 which was carried out in 2006 at the ISTA at TU Berlin. The data was used for validation of turbulence modeling approaches (RANS, DES, LES) which is reported in an accompanying publication [2].

2 MOTIVATION AND SET-UP

The experiment was tailored around existing 1:7 scale wooden models of two typical ICE 3 bogies. The generic underfloor geometry should

- include typical flow features of the underfloor region of a train which challenge CFD,
- provide boundary conditions which could be easily realized in a CFD model,
- allow easy access for LDA from different sides, and
- provide detailed profiles of mean velocity and turbulence statistics.

Fig. 1 shows a sketch of the geometry which consists of two bogie cavities that are connected by ducts and separated by a larger empty cavity which mirrors the cross-sectional changes at the connection of two coaches of the ICE 3. The coupling rod was modeled by a cylindrical stick. Inside the first bogie cavity the asymmetrical motor bogie with a pair of engines and gear boxes is placed whereas the second cavity holds the symmetrical trailer bogie with disk brakes and the eddy-current brake.

Clearly, the “channel” situation differs strongly from the one under the real train due to the presence of an axial pressure gradient and lateral obstruction of the flow by the side walls. Nevertheless, some features such as the formation of shear-layer at sharp edges, the flow around obstacles such as the wheels, and the existence of flow from the trackbed side in an out of the cavities should be qualitatively similar.

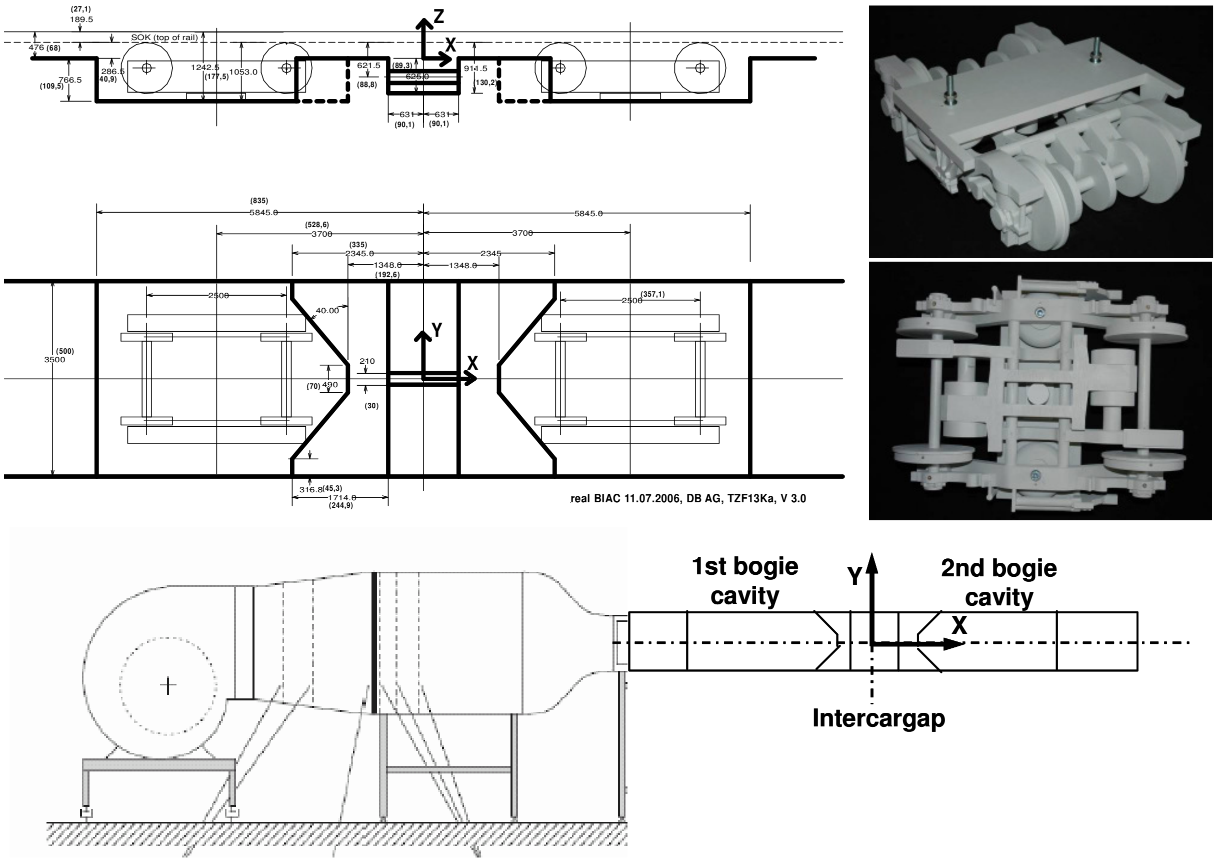

Figure 1: Generic underfloor geometry consisting of two bogie cavities separated by a third cavity in the center representing the intercar gap. The flow is from left to right. The motor bogie sits in the left cavity.

Fig. 1 also shows the set-up in the laboratory. Air from the centrifugal blower enters through screens into the axial-symmetric settling chamber. It passes through a contraction and enters a rectangular duct with a gap width of $h = 68\ mm$ which corresponds to a distance of

476 mm (in 1:1) between the underbelly of a coach and the trackbed. The latter is represented by a flat, smooth wall. Rails are not modeled and the wheels are at rest. The overall dimensions of the test section are 500 mm in the lateral direction and 2438 mm in the axial direction, including the 250 mm and 500 mm long inlet and outlet.

3 RESULTS

The flow speed was measured with a two-component LDA from Dantec Systems with a 300 mW air cooled argon ion laser in backscatter mode. The beams had wavelengths of 514,4 nm (LDA 1) and 488 nm (LDA 2) and the focal length of the optics was 310 mm. The flow was seeded with a spray of DEHS that was directed into the inlet orifice of the blower. Optical access to the model was either provided through lateral walls or through the flat wall representing the trackbed.

The flow in the inlet duct is fairly uniform across the channel, allowing to specify plug flow of magnitude $U_{ref} = 25{,}5\,m/s$ with superimposed low-level turbulence intensity of $u_{rms}/U_{ref} = 0{,}028$ as inlet boundary condition in the CFD.

Fig. 2 gives an impression of the wide variety of flow patterns encountered in this configuration. Pdfs of the velocity are often non-Gaussian, non-symmetric, and occasionally bi-modal as in the vicinity of the bogie frame or downstream of the wheels.

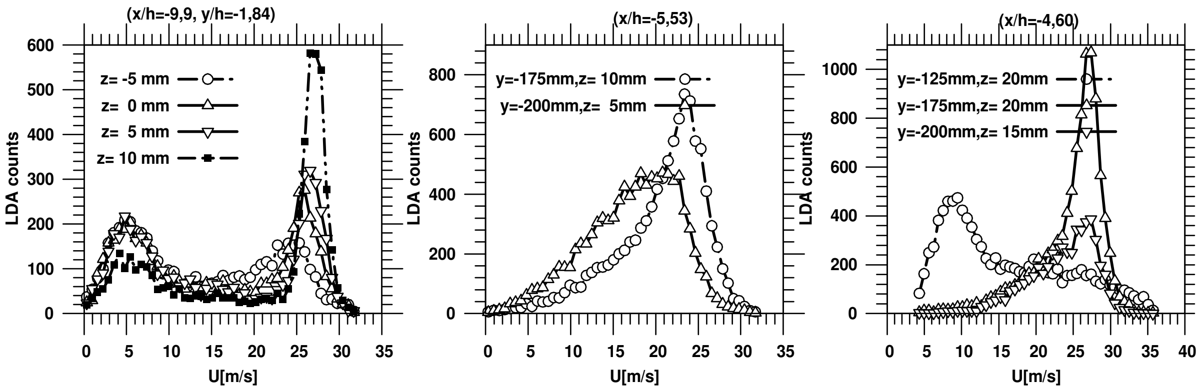

Figure 2: Distribution of the axial velocity at several positions in the first bogie cavity.

Mean flow and turbulence intensity profiles along *z* have been measured at the nodes of a 50 mm by 50 mm "grid" in the *x,y*-plane. Some examples are shown in Fig. 4 from the funnel-shaped end region of the first bogie cavity and from the central cavity. The flow separates at the rearward blunt face of the first bogie cavity and a small separation bubble forms along the "train" underside downstream of the funnel. There, the r.m.s. of the axial velocity component reaches high values up to 50% of the bulk velocity U_{ref}.

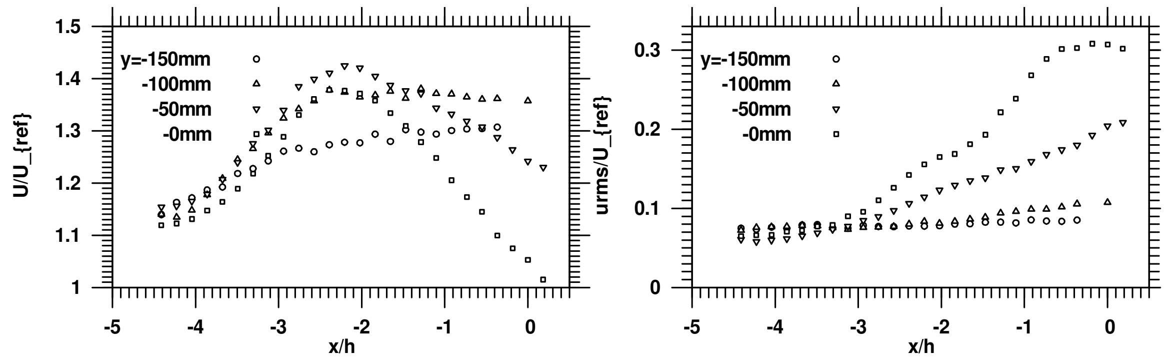

Figure 3: Profiles (along x) of the mean (left) and the rms (right) of the axial velocity component at several lateral positions close to the flat rear wall of the rig (*z/h = 0,91*) which represents the trackbed.

A free shear layer forms over the central cavity and the flow recirculates at the bottom of this cavity. In this region, the maximum turbulence intensity reaches up to 30% of U_{ref}.

Fig. 3 shows part of the flow evolution along the "trackbed". The "vectoring" of the outflow from the funnel-shaped end of the bogie cavity causes a 30% increase of the near-wall mean flow in the region *-100 mm < y < 100 mm.* In addition, the fluctuation intensity u_{rms} more than triples along the centerline of the duct. This might be relevant for the assessment of the aerodynamic load on the trackbed with respect to ballast projection.

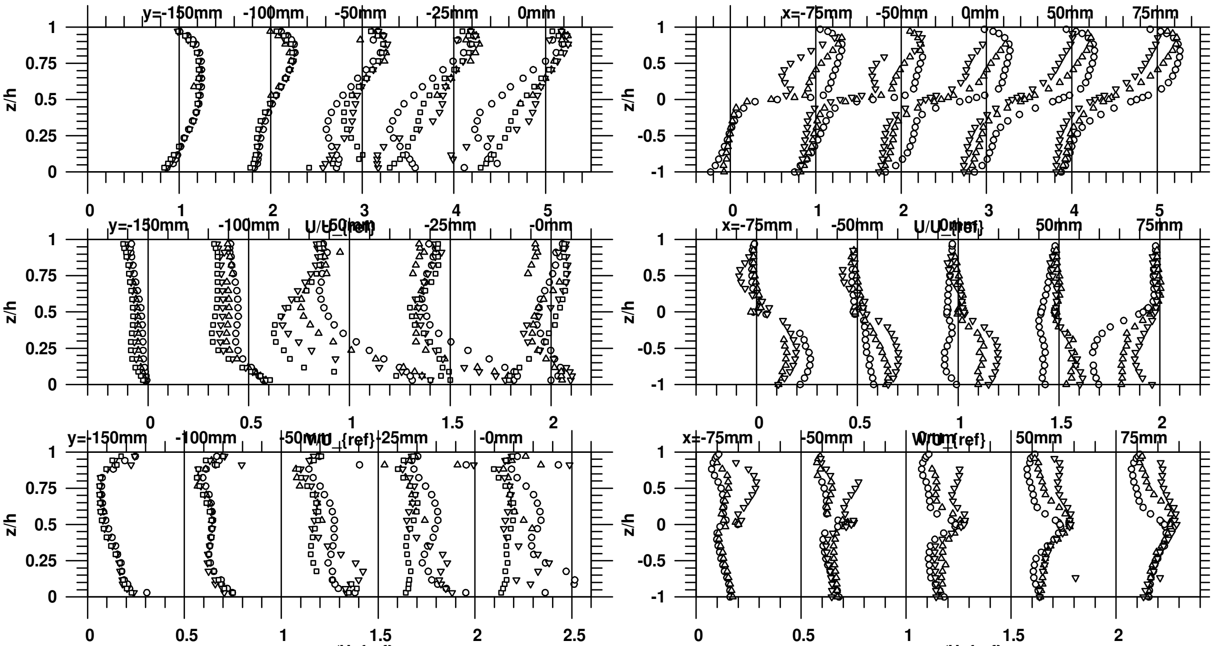

Figure 4: Left: Profiles (along z) of mean flow components *U(z)* (top) and *V(z)* (middle) and turbulence intensity $u_{rms}(z)$ (bottom) over the funnel-shaped end of the first bogie cavity at x = -100 mm (o), *-150 mm* (Δ), *-175 mm* (∇), *-200 mm* (□). Right: Profiles (along z) of mean flow components *U(z)* (top) and *W(z)* (middle) and turbulence intensity $u_{rms}(z)$ (bottom) over the central cavity representing the intercar gap for *y = -200 mm* (o), *-100 mm* (Δ), and *-50 mm*(∇).

4 SUMMARY

Flow along a generic underfloor geometry in scale 1:7 has been investigated in order to provide detailed and reliable measurements of mean flow and turbulence intensity for the validation of turbulence closures [2] to be applied in CFD of full train sets in 1:1. More profiles and flow visualizations (surface streamlines) will be shown in the full paper.

ACKNOWLEDGEMENTS

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