BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

CROSS-COMPARISON OF MEASUREMENT TECHNIQUES FOR THE DETERMINATION OF TRAIN-INDUCED AERODYNAMIC LOADS ON THE TRACKBED

Peter Deeg*, Mattias Jönsson˜, Hans-J. Kaltenbach*, Martin Schober† and Marco Weise†

*Deutsche Bahn AG, DB Systemtechnik
Aerodynamics and Air Conditioning, Völckerstraße 5, 80939 München, Germany
e-mail: peter.deeg@bahn.de, hans-jakob.kaltenbach@bahn.de,

† Bombardier Transportation MLN/TSSA,
Am Rathenaupark, 16761 Hennigsdorf, Germany
e-mail: martin.schober@de.transport.bombardier.com, marco.weise@de.transport.bombardier.com

˜Deutsches Zentrum für Luft- und Raumfahrt
AS-TS, Bunsenstraße 10, 37073 Göttingen, Germany
e-mail: mattias.joensson@dlr.de

Keywords: Track-side measurement, ultra-sonic anemometer, load on track bed

1 INTRODUCTION

Recently, the interest in a deeper understanding of underfloor aerodynamics of high-speed trains has increased due to the occurrence of several ballast projection incidents in European countries and Korea [1, 2]. Despite the fact that not all factors contributing to the phenomenon have been identified – ranging from infrastructure aspects to the role of excitation of the trackbed during train passage up to differences in the underbelly design of vehicles – it is well understood that the aerodynamic load imposed on the trackbed is one of the key factors. Within the context of geophysics and building aerodynamics the friction velocity has been identified as critical parameter for the onset of particle dislodgement from a gravel bed subject to a tangential air stream [3, 4]. Since the wall stress is difficult to measure it is desirable to identify other relevant flow parameters.

This paper reports on the outcome of a trackside measurement campaign carried out as part of the research cooperation "Aerodynamics in Open Air" in the spring of 2006 on the high-speed line connecting Florence and Rome. The site was located close to the Terranuova Le Ville tunnel and incorporated segments of ballasted track and of slab track.

The study served several goals, namely to find out

- what fundamental quantities such as static pressure, air speed, and wall stress could be measured under a passing train and what accuracy respectively temporal/spatial resolution could be achieved with different techniques,
- what statistical measures (types of averages) could be derived to assess the flow field,
- how the flow evolves along the train and whether an asymptotic state develops,
- to what degree the flow varies in the lateral and vertical direction under the train, and
- how the ground roughness affects the flow and how quickly the flow adapts to a sudden change in roughness at the interface from ballasted to slab track.

2 SET-UP AND MEASUREMENT TECHNIQUES

Fig. 1 shows two examples of the measurement devices installed in the trackbed, namely lateral and vertical rakes of Pitot and Prandtl tubes and a special design of a 2D ultra-sonic anemometer with a temporal resolution of approximately 250 Hz. The resonance frequency of the various pressure probes was determined to be in the range 200 Hz to 360 Hz.

Figure 1: Installation of a Pitot tube rake (left) and of a 2D-Ultrasonic-Anemometer on slab track.

The probes and the data acquisition equipment must be robust due to disturbances from the presence of ground vibrations, of dust, and of strong electromagnetic fields.

3 RESULTS

Measurements were recorded from regularly passing trains which differed considerably with respect to the train speed. Thus, ensemble averages have to be built for non-dimensional coefficients such as $c_p = (p - p_0)/(0.5\rho\, u_{train}^2)$ and $c_U = u / u_{train}$ assuming Reynolds number independence. Between 30 and 35 passages of trains of the ETR 500 series in the speed range $190\ km/h < u_{train} < 250\ km/h$ were selected for the computation of ensemble averages.

Fig. 2 shows time traces of velocity signals recorded with different probes. The USA signals shows that the axial flow speed quickly rises to a level around which it fluctuates. The flow is highly turbulent and lateral fluctuations are nearly as intense as the axial fluctuations.

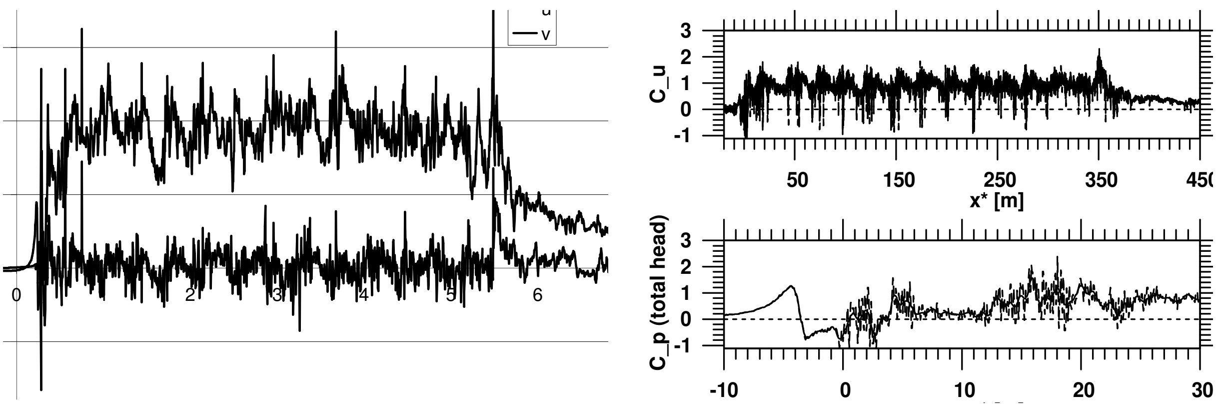

Figure 2: Left: raw data from USA for axial and lateral flow speed near top of rail vs. time (in s). Right: Raw data from Pitot tubes without (dashed) and with (solid line) a 75-Hz-low pass filter versus axial position (in m) under the train.

Clearly, the Pitot tube signal is spoiled by the presence of resonances which are not related to changes in the flow speed. Two methods have been found to be very effective in cleaning the signal. Use of a 75 Hz-low-pass filter eliminates all spurious oscillations from the instantaneous signal. Alternately, one can form phase averages from the static and total pressure recordings, respectively c_p, first and derive the average flow speed afterwards as

$$\overline{C}_U^{corr} = \sqrt{\left(\overline{c}_{p,tot} - \overline{c}_{p,stat}\right)}\sqrt{\frac{1}{1+T_{rms}^2}} \qquad (1)$$

with a correction based on estimation of the turbulence intensity $T_{rms} = (\overline{u_i' u_i'})^{0.5} / \overline{U}$.

In Fig. 3 ensemble averages are compared for three probe types at the same vertical and lateral position. During passage of the head a short flow reversal occurs which can not correctly be captured by the pressure probes. Nevertheless, as the flow (in the average) approaches an asymptotic state for $x > 50\,m$ with a regular pattern in the flow variation from coach to coach the obtained ensemble averages are very similar for the three probe types. Also, a similar magnitude for the peak value at the train's tail is predicted.

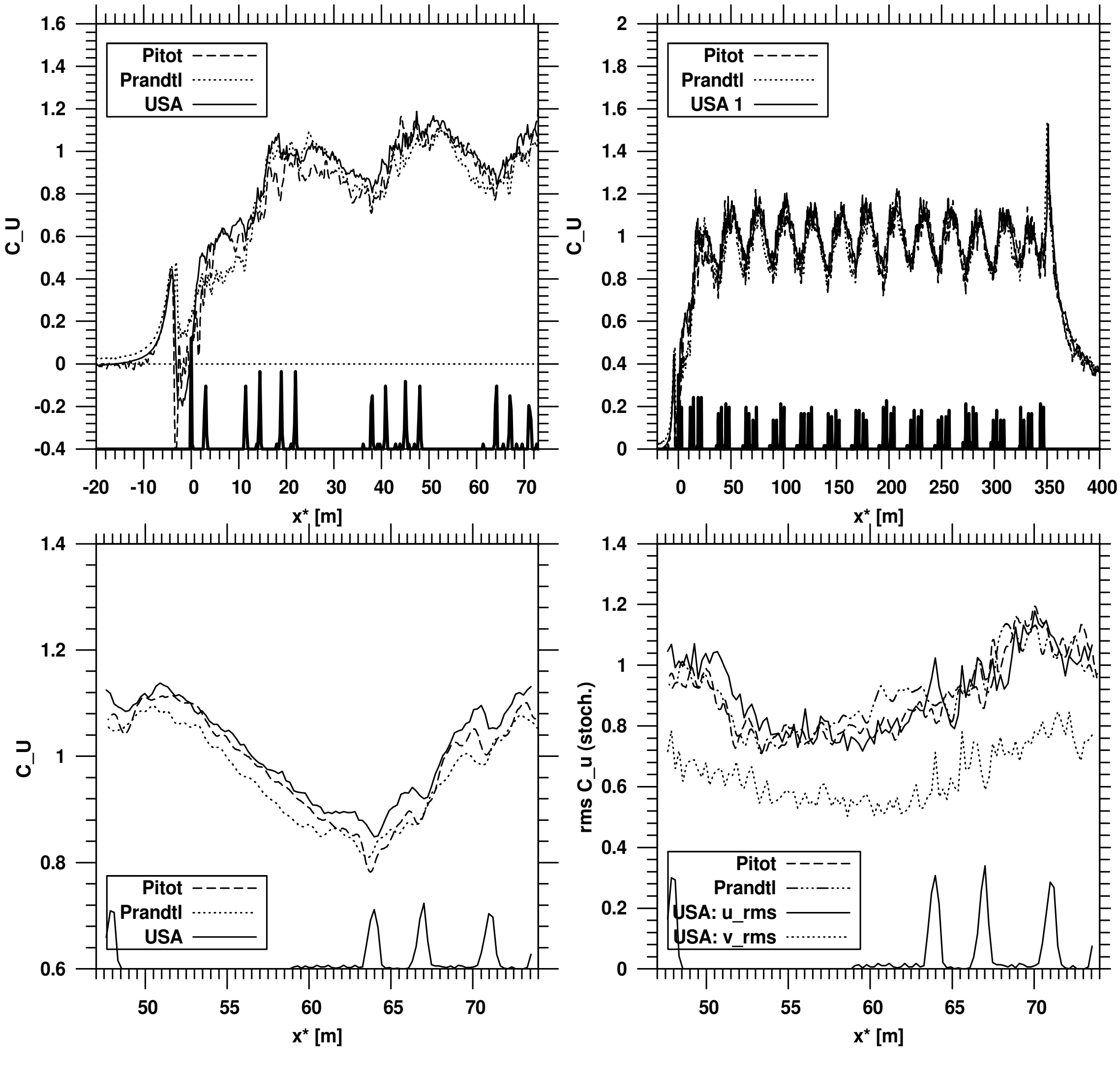

Figure 3: Ensemble averages (top) and phase averages (bottom) of the axial speed and the r.m.s. of stochastic fluctuations (in arbitrary units) obtained from 75 Hz-low-pass filtered pressure recordings and unfiltered USA data near top of rail vs. distance under train. At the bottom of each figure the axle positions are shown.

The development of a regular pattern allows further comparison on the level of phase averages (defined in the region $49{,}75\,m < x < 309{,}25\,m$) for 10 consecutive coaches. Fig. 3 (bottom) shows an example. The influence of the bogies with respect to enhancement of turbulence intensity and axial speed can be identified. Under the smooth part of the coach underside the flow relaxes towards lower speeds. The USA yields some information on the degree of anisotropy of the fluctuations.

The triple decomposition of the signal in "coach" average, i.e. the mean over a coach, phase average, and stochastic fluctuation allows a comparison of the magnitude of coherent and stochastic contributions to the turbulence intensity. This is done in Table 1.

With respect to the mean of C_U the probes differ by 5%. For the coherent and stochastic parts of the velocity fluctuation the predictions of the three probes are very similar. This indicates that all three probe types are suitable to assess flow variations in the frequency range below 100 Hz. Knowing that the probes have not resolved the entire spectrum of turbulence they yield an estimate for the lower limit of the stochastic fluctuations. According to Table 1 the r.m.s. of the stochastic part of the axial speed is at least twice as large as the coherent part associated with the regular passing of bogies and cross-sectional changes at the intercar gap.

Table 1: Comparison of train (or coach)-averages of axial speed and the r.m.s. of coherent and stochastic fluctuations at three lateral positions near top of rail, normalized by c_u at y=0mm. Averages are computed from 75 Hz low pass filtered pressure data, according to eq. (1) with $T_{rms} = 0$, and from unfiltered USA data.

Lateral position y*	Probe	c_U		rms coherent		rms stochastic
		Low pass 75 Hz	Eq. (1)	Low p. 75 Hz	Eq. (1)	Low p 75 Hz
0mm	USA 2	100.0 %		6.9 %		14.9 %
	Prandtl 4	97.5 %	98.5 %	6.8 %	6.9 %	14.5 %
	USA 2/ Prandtl 4	**1.026**	**1.015**	**1.0164**	**0.9902**	**1.0266**
-200mm	USA 3	97.5 %		8.3 %		14.7 %
	Pitot 131	95.9 %	97.0 %	8.2 %	8.3 %	14.8 %
	USA 3/ Pitot131	**1.017**	**1.005**	**1.0089**	**1.0050**	**0.9935**
-400mm	USA 1	94.8 %		8.2 %		15.1 %
	Prandtl 1	90.4 %	91.7 %	8.2 %	8.2 %	15.6 %
	Pitot 141	92.4 %	93.6 %	8.8 %	8.9 %	15.5 %
	USA 1/ Pitot 141	**1.026**	**1.013**	**0.9272**	**0.9177**	**0.9780**
	USA 1/ Prandtl 1	**1.049**	**1.034**	**0.9947**	**0.9986**	**0.9693**
	Prandtl 1/ Pitot 141	**0.978**	**0.979**	**0.9322**	**0.9190**	**1.0089**

4 CONCLUSIONS

It has been demonstrated that classical pressure probes as well as high-frequency ultrasonic anemometers are suitable devices for the assessment of the average air speed above the trackbed. However, care has to be taken if details in the nose region of the leading vehicle come in to focus where local flow reversal occurs. Fluctuations up to a frequency of 100 Hz could be resolved, allowing to distinguish coherent and stochastic contributions.

ACKNOWLEDGEMENTS

We thank Roberto Roberti and Luca Bocciolini from Trenitalia and Mario Testa from RFI for their dedication in organising of the test campaign. Partial funding under grants 19 S 5009 A and 19 S 5009 B from the German Ministry of Economics is acknowledged.

REFERENCES

[1] H. B. Kwon, C. S. Park.: An experimental study on the relationship between ballast-flying phenomenon and strong wind under high-speed train. *Proc. of the WCRR 2006, Montreal, nbr. 625.*

[2] ICE-3-Zulassung in Frankreich vor dem Abschluss. *Eisenbahn-Revue 10/2005.*

[3] Kind, R. J.: Tests to determine the wind-speeds for scouring and blowoff of rooftop gravel. *Proceedings of the Fourth Intern. Conference on Wind effects on buildings and structures.* Heathrow, 1975. Eds.: K. J. Eaton. Cambridge Univ. Press, pp. 591-604.

[4] Anderson, R.S., Sorensen, M., Willetts, B.B.: A review of recent progress in our understanding of aeolian sediment transport. *Acta Mechanica [Suppl.],* **1**, 1-19, 1991.