Proceedings of the 4th WSEAS International Conference on Fluid Mechanics and Aerodynamics, Elounda, Greece, August 21-23, 2006 (pp26-28)

Slipstream Velocities Induced by Trains

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Abstract: - This paper summarises results of several experimental investigations on draught air flows induced by rail vehicles (slipstream effect). In addition to full-scale track-side measurements, model-scale experiments have been carried out in a conventional wind tunnel. The overall aim of the model tests is to capture the physics of the flow field induced by a train and to identify the relevant parameters which determine the slipstream behaviour of a vehicle.
Experimental results are reported for track-side tests using according to the upcoming European homologation standard TSI HS RST [1] to ensure the safety of passengers waiting on a platform. Furthermore, the influence of tail shape details of a regional train on slipstream velocities induced in its wake has been investigated in a wind tunnel employing a scale 1:20 train model. Flow velocities were measured using a hot-wire probe that was traversed within the wake region. Both oil paint and smoke visualisations were used to investigate the structure of the flow field in the wake. The results show, that different types of wake pattern can be distinguished. A comparison of the methods is given.

Key-Words: - Slipstream, Railway, Wake flow, Tail shape, Wind tunnel, Moving model rig

1 Introduction

A passing train is inducing draft air flows (henceforth quoted slipstream) and pressure fluctuations in its immediate vicinity. These slipstreams and pressure fluctuations are generating forces on persons waiting on a platform, trackside workers, stationary objects and track infrastructure. The forces can be of significant strength and may damage trackside structures and cause destabilisation of persons (cf. [2]).
The aerodynamic loads on passengers on a platform are a safety relevant issue (cf. [3]) and hence treated by European legislation, e.g. the Technical Specification of Interoperability. Temple and Johnson [4] stated that the slipstream induced by rail vehicles has a much stronger influence on the stability of persons than the short term pressure fluctuations.
According to Baker [5], the passage of a rail vehicle can be divided into five regions as depicted in Fig. 1:

1. Upstream region
2. Nose region
3. Boundary layer region
4. Near wake region
5. Far wake region

The first two regions are associated with strong pressure fluctuations. The three more downstream regions are, in contrast, dominated by the slipstream. The exact position at which the strongest slipstream occurs is strongly dependent on the type of train. Freight trains usually show the maximum in the boundary layer region, smooth passenger trains show it in the wake regions.

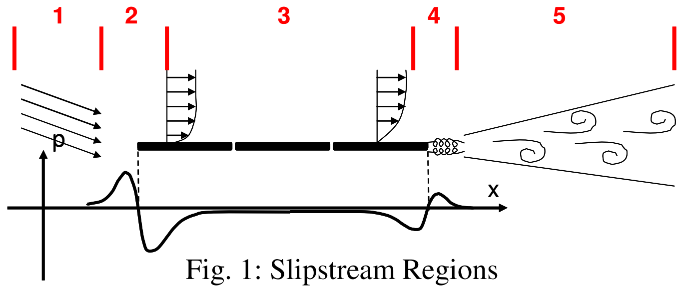

Fig. 1: Slipstream Regions

While the slipstream intensity depends strongly on a series of operational parameters such as the train speed or cross-wind (cf. [2]), one of the most important vehicle related factors is the shape of its tail.
Nowadays trains have to be designed such, that their slipstream intensity does not exceed a certain value which is recognised as save for people. Therefore, a train design has to be assessed with regards to its impact on induced air flows in an early design stage. For the homologation of rail vehicles full scale tests are required. To avoid failure of homologation tests, which would mean costly retrofits and late delivery, quite accurate and reliable prediction methods are required in the design process.

2 Motivation

Homologation requirements for interoperable railway traffic have been formulated in the TSI HS RST [1] (Technical Specification for interoperability, High-Speed Rolling-Stock). According to this new TSI, interoperable

trains within Europe have to be homologated with respect to slipstream effects.
The TSI requires a full-scale track-side test (cf. [1], [6]). The test is carried out using appropriate air speed probes, such as ultrasonic anemometers. For passengers standing on a platform, the probes are installed 1.2 m above a platform and 3.0 m beside the track centre. The sensor signal has to be sampled with at least 10 Hz and low pass filtered using a moving average of 1s. The induced airflow is measured during a full train passage including a timeframe from 1 s before the train head passes the sensor until 10 s after the tail passage. At least 20 independent measurements under similar conditions have to be taken into account for the assessment of the slipstream intensity. From each individual measurement, the maximum air speed has to be determined from the filtered signal. The relevant slipstream velocity is calculated by averaging all individual measurements (ensemble average) and taking into account a confidence interval of 2σ, thus:

$$u_{2\sigma} = \bar{u} + 2\sigma \quad (1)$$

with
$\bar{u}$: average of maximum values of all air speed measurements
σ : standard deviation of all air speed measurements.
This means, that the result of the test depends on the scatter of measurements and therewith on the quality of the test implementation and ambient conditions, e.g. ambient wind. The TSI requires the slipstream velocity not to exceed $u_{2\sigma}$ = 15.5 m/s at the platform (cf. [6]).
For the design process of rail vehicles, a test scenario as described above is disadvantageous, since full scale tests would require a 1:1 prototype and impose high costs if parameter variations are necessary. Thus, appropriate and reliable quantification methods for slipstream effects have to be used during the design process, e.g. scale-model tests.
For model scale experiments, the proper representation of all relative speeds between train, ground and air is challenging and requires either a moving model rig or a moving belt setup. Thus, scale tests usually inhere major deviations from full scale conditions. Some of these typical deviations are:

- Significantly lower Reynolds numbers
- Shorter trains
- Relative movements of train, ground and air are not completely respected.

However, it seems appropriate to perform conventional wind tunnel tests to capture the physics of the flow field in a train-fixed frame of reference in which the slipstream phenomenon is stationary. The influence of these deviations from full scale conditions has to be taken into account when assessing model scale results.

3 Results

Since the slipstream of a train is a very complex phenomenon, different aspects of this problem need to be investigated separately. Therefore, different experimental setups have been used to investigate several aspects of induced air flows:

- Full scale tests in accordance with the TSI HS RST
- Wind-tunnel tests in scale 1:20 using a 3-car train set and a flat and stationary ground

3.1 Full Scale Test

A full scale test has been carried out to gain experience with the TSI setup. Different train types and configurations have been tested. Beside ultrasonic anemometers also hot wire probes have been installed along the track to compare the two measuring techniques. Furthermore, hot wire probes allow higher sampling rates, which gives additional information about transient flow properties.
A typical time series of a 10 Hz ultra-sonic anemometer signal generated by a passenger train with a relatively smooth surface is plotted in Fig. 2. The five different slipstream regions can be clearly distinguished. It is obvious that highest slipstream velocities occur in the near wake region behind the train. In comparison to other regions, increased slipstream velocities are more persistent in the wake (region 4), which leads to significantly higher values in the 1 s moving average. These long-term air flows have the strongest impact on the destabilisation of people.

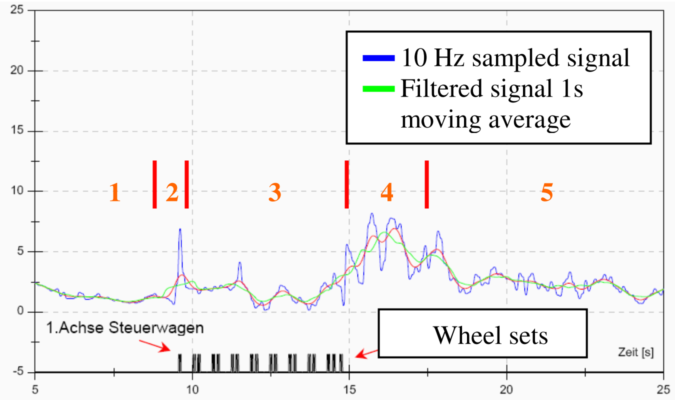

Fig. 2: Time signal of full-scale test

3.2 Wind-Tunnel Test

Wind-tunnel test are most suitable to investigate the flow field in the train-related reference frame. In this case it is an advantage, that a probe can be easily positioned at a fixed location relative to the vehicle.
A wind-tunnel test has been performed, in which the near wake region has been scanned by means of a traversed

hotwire probe (cf. Fig. 3). In addition to this, flow visualisations have been generated by means of the smoke (cf. Fig. 4) and the oil-paint techniques (cf. Fig. 5).
Different tail shapes, typical for regional trains, have been investigated during the test. Depending on minor features of the tail shape, two different wake patterns could be identified (cf. Fig. 3 and 5). These findings are in line with the experimental investigations by Morel [7], who showed that there exist two distinct types of wake flow patterns behind test bodies similar to rail vehicles:

- Quasi axis-symmetric separation bubble behind blunt, sharp edged tails (Pattern I)
- Fully 3-D wake flow with characteristic vortex shedding at the side edges or radii behind distinctly inclined rearward faces (Pattern II)

No intermediate flow patterns have been observed. Once established, each of the two flow patterns is stable. In Fig. 5 the width of the wake is indicated at a distance of 4.5 vehicle widths behind the tail. The wake is 40% wider in flow pattern II compared to the wake observed in flow pattern I. This also corresponds with the different widths of the velocity profiles plotted in Fig. 3.
Since most available test results have been gained for simple generic train shapes focusing on drag reduction, the difficulty is to transfer these results to the slipstream properties of real and more complex trains and tail geometries. While simple geometries are often investigated with regards to one single shape parameter (e.g. slant angle of tail face), real trains feature several relevant shape parameters, which need to be identified for different types of rail vehicles.

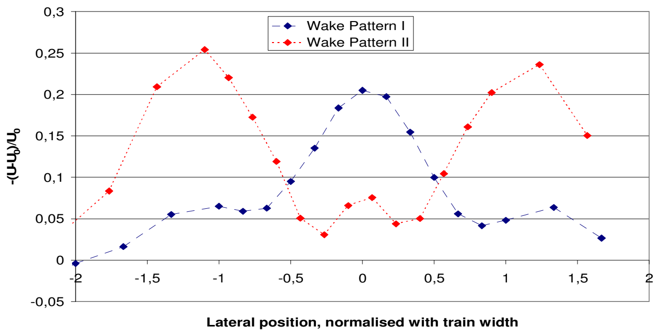

Fig. 3: Velocity profile in the wake of a train

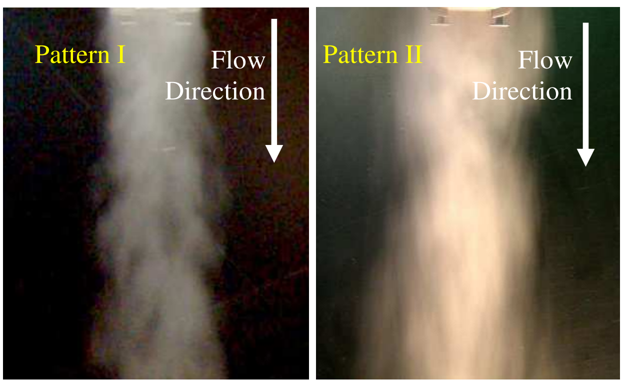

Fig. 4: Smoke visualisation in the wake region

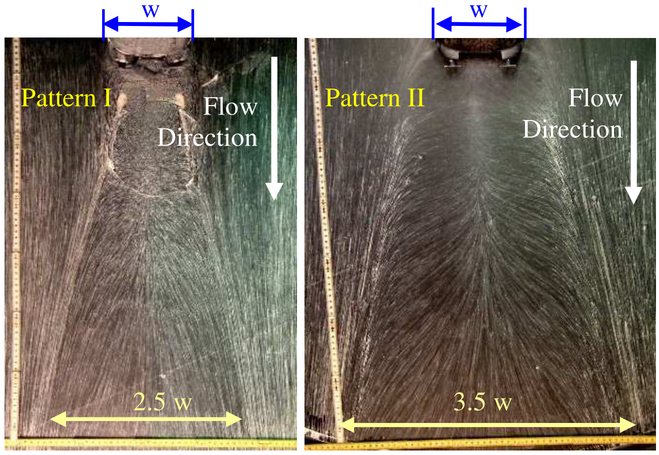

Fig. 5: Oil paint visualisation: footprints of the wake flow

4 Conclusion

Both full-scale tests and scale-model tests have been successfully carried out to investigate the slipstream behaviour of rail vehicles. While full-scale test are necessary for the homologation of rail vehicles, wind-tunnel tests are appropriate to investigate single aspects of slipstream in more detail and to predict the slipstream behaviour of a train during the design process. The influence of several tail-shape features of a regional train on the slipstream generated in its wake has been investigated. Different types of wake flow have been observed.

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