Better understanding of high speed train slipstream velocities.

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Summary

There is renewed interest from European railways in understanding the mechanisms of the slipstreams generated by trains. This interest arises from the potential danger to staff at trackside and passengers on station platforms, which has been recognised since high-speed train operations began. Incidents involving children's lightweight pushchairs in several countries have highlighted the problem and the introduction of higher train speeds in European countries has further stimulated the desire to understand the phenomenon in greater detail. The recent introduction of the high-speed train Technical Specifications for Interoperability has shown that there is a lack of agreement on exactly how to determine the safety of people exposed to train slipstreams.

This paper puts information gathered in the recent 5th Framework EC project, RAPIDE, into the public domain to help improve understanding of how the basic physical processes of high-speed train slipstreams vary with systematic parameter changes.

The AEA Technology Rail Moving Model Rig, (a facility that was principally designed to study train-tunnel pressure interactions), was used for a series of model scale tests for slipstream velocity measurements, and has been generally validated in the RAPIDE project. Hot-wire measurements were made of the air velocity variations as parameters were changed, to investigate their influence on the train slipstreams. The effects of variations with distance from a platform edge, platform height, train type and between two passing trains are described in this paper.

Keywords

Aerodynamics, slipstream, RAPIDE, Moving Model Rig, platform, trackside.

1 Introduction

1.1 RAPIDE Project

The RAPIDE Project, (Schulte-Werning et al 1999), was a three year EC co-funded project under Brite-Euram III, with a variety of partners from European railways; (Deutsche Bahn AG, SNCF, Trenitalia), and other European railway organisations; (AEA Technology Rail, MIRA, RUAG and Bombardier).

Part of the programme of studies consisted of investigation the slipstreams of high-speed passenger trains and consisted of a series of full-scale tests in Germany, complemented by scale moving model slipstream measurements.

1.2 Moving Model Rig

The MMR consists of two 150 m long tracks, along which train models can be fired at full scale train speeds. About a third of the track length is required for the acceleration of the models, the central third comprises the test section and the final third is needed to decelerate the trains.

The MMR was originally conceived as a facility to study train-generated pressures in tunnels and to ensure that the pressure waves are correctly phased with the train movement, actual full-scale speeds are necessary to ensure Mach number similarity with full-scale.

The power for the models is supplied by bungee rubbers using a catapult principle and train speeds up to 270 km/h can be easily achieved. However, gearing is necessary to prevent over-rapid acceleration and deceleration, which potentially could damage the models. The train speed is nearly constant along the test section if no tunnel is mounted. Braking is achieved by the model picking up a link to a piston that is being drawn into a deformable tube and the model kinetic energy is thereby dissipated.

The MMR has been used extensively for determining train aerodynamic characteristics in tunnels and in the open air (pressures). Pressure measurements in both types of tests have been validated against full-scale data. Further information about the MMR can be found in Dalley and Johnson (1999).

Within RAPIDE, slipstream velocities around an ICE 2 train model were studied extensively and compared with full scale. Validation of the MMR measurements with full scale was an important outcome of this part of the project, (see Johnson et al, 2003).

As a further part of RAPIDE, Moving Model Rig tests were scheduled to include a parametric study. The study investigated:

- The effect of platform height on platform slipstreams
- Train design variation with effect on platform slipstreams
- 2 passing trains in the open
- Tail pressure measurements on ICE 2 in the open

2 Tests

2.1 Train models

Models of the leading and trailing vehicles and two intermediate vehicles of the German ICE 2 and the French TGV were made at 1/25 scale and used for this study.

2.2 Programme

The inherently chaotic nature of slipstream data requires that, for valid interpretation of slipstream velocities of any model/platform configuration, analysis should be based on at least 10 sets of data from 10 firings of the model at the same velocity, (Baker et al 2001).

Hence, the test programme was as follows:

Description	Number of Tests
ICE 2 platform slipstreams (German height platform) Repeated test with model velocity: 50 ± 1 m/s	10
ICE 2 platform slipstreams (UK height platform) Repeated test with model velocity: 50 ± 1 m/s	10
TGV platform slipstreams (UK height platform) Test with model velocity: 50 ± 1 m/s	10
2 trains passing: ICE 2 passing ICE in the open ICE 2 velocity: 50 ± 1 m/s ICE velocity: 50 ± 1 m/s	4

3 Slipstream Velocity Measurements

Slipstream velocities were measured using hot-wire anemometry. The hot-wire probes used were 2-dimensional and measured the magnitude of the total combined air velocity adjacent to the passing train in the longitudinal and lateral direction. That is to say that the velocities measured were in the directions parallel and perpendicular to the side of the train. The velocity output was the combined magnitude of these two velocities.

The probes were positioned on the model-scale platform at locations equivalent to those used in the full-scale tests at Meitingen in Germany. The scale platform heights were equivalent to a German height platform, (0.31m above rail level), and to a standard UK platform height, (1.0m above rail level).

In the MMR tests, three hot-wire probes were used in each case, positioned at various locations from the edge of the platform. These positions were, (equivalent to full-scale): 1m, 1.5m and 2m from platform edge. The probes were positioned at a height equivalent to a full-scale height of 1.335m above the platform. The probe locations are shown in Figures 2 and 3.

For the passing trains study, a rake of hot-wire probes was suspended at the crossing point of the two models. The rake consisted of 5 hot-wires, oriented to measure the velocity in the longitudinal direction parallel to the two passing trains. The rake was positioned central to the passing models with reference to the track centre-lines with the probes at a full-scale height of 1.3 m above rail level. This height was based on the approximate height of the chest of an average human being. The track spacing, centreline to centreline, was equivalent to 5.375 m at full-scale.

3.1 Platform Slipstream Data

3.1.1 Summary of tests

- Three measurement positions at full-scale 1m, 1.5m and 2m, (1/25th model-scale: 40mm, 60mm and 80mm), from the platform edge. Full-scale height was 1.335m above platform.
- German height platform, 0.31 m above rail level
  - 10 firings with ICE 2 model at 50 m/s.
- UK height platform 1.0m above rail level.
  - 10 firings with ICE 2 model at 50 m/s.
  - 10 firings with TGV model at 50 m/s.

Figure 1*: Schematic representation of different platform heights and hot-wire probe positions*

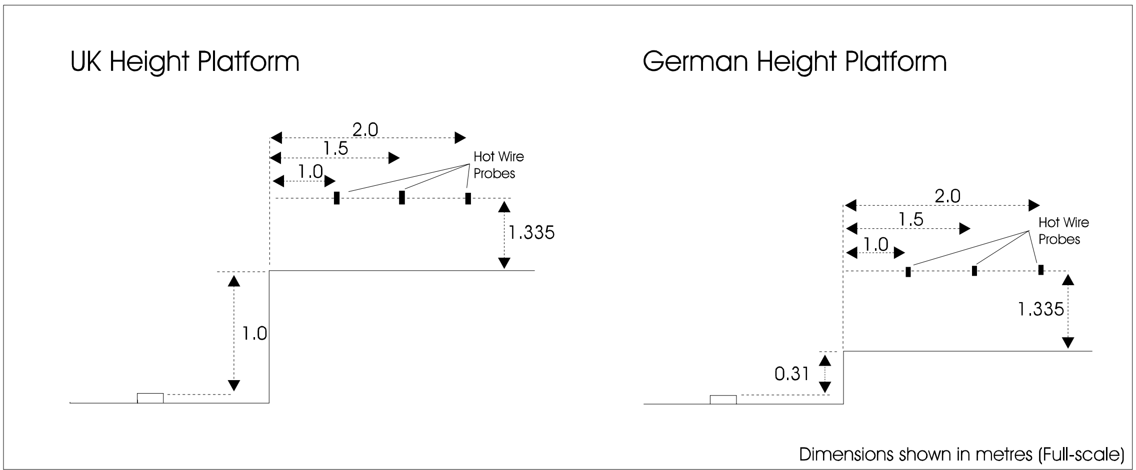
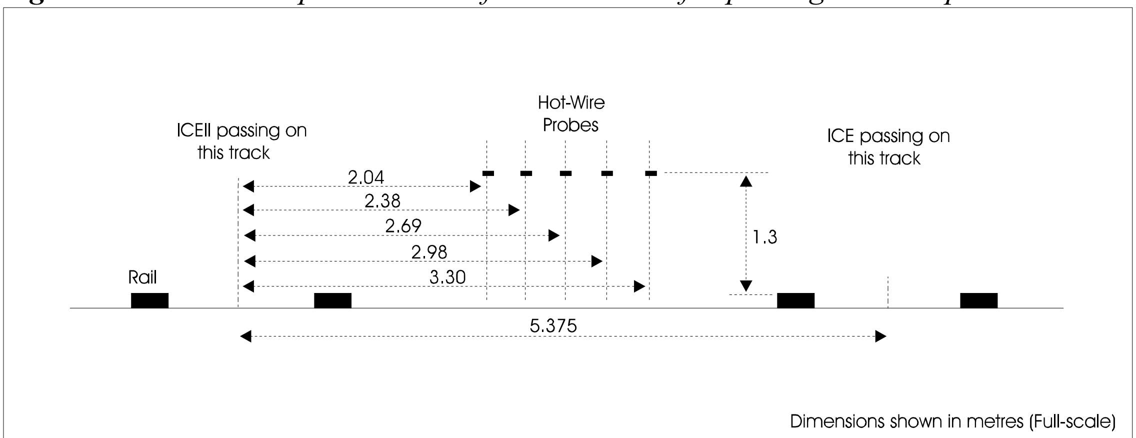


Figure 2*: Schematic representation of hot-wire rake for passing trains slipstreams*



3.1.2 Data analysis

The platform slipstream data for each different train (TGV and ICE 2) is based on averaging 10 repeat firings and 10 corresponding sets of data at nominal train speeds of 50 m/s. For the averaging calculation, the time scales were aligned using the passing event pulses for each firing. An extract from the results is presented in Figures 3, 4, 5 and 6, where the slipstream velocities measured at 1 m and 2 m (full-scale) from the platform edge are shown.

3.2 Passing trains slipstream data

3.2.1 Summary of Tests

- Five measurement positions central to track centre-lines at a full-scale height of 1.3m above rail level.
- 4 firings with passing ICE model at 50 m/s passing ICE 2 model at 50 m/s.
- Track spacing (centre-line to centre-line): 5.375 m.

3.2.2 Data Analysis

Although it was possible to determine that the trains crossed at the position of the hot-wire rake in each of the four passing runs, it was not possible to determine where the noses or tails passed each other relative to the hot-wire rake. That is to say, it was impossible to determine accurately which part of the trains crossed at the hot-wire position. This prevented the previously described statistical description of the resulting slipstream data. Therefore, only a single set of results for the passing trains is presented for information in Figure 7. These are unprocessed data from a single location, approximately at the mid-point between the two tracks.

Examination of these results shows the chaotic nature of the combined effects of the passing and interacting trains slipstreams. It is not possible to discern the crossing event with any accuracy, obviating the possibility of aligning the time histories and analysing the results statistically. The results should therefore be only regarded as indicative, but they do indicate the magnitudes of the air speed in the between train region.

4. Discussion

4.1 ICE 2 passing a German Height Platform

In Figures 3 and 4, the averaged slipstream speeds are shown for the ICE 2 passing the station with a German height platform. The slipstream is characterised by a potential flow velocity peak as the train nose passes the measurement location, (at approximately 0.15 seconds). There is a gradual speed increase as the train passes and then a second potential flow velocity peak as the train tail passes, at about 0.22 seconds. After this there is a further rise in speed until a peak value is reached, just before 0.3 seconds, after which there is a decay in the velocity, which persists well over 50 seconds (full scale time).

It is important to note that the maximum peak slipstream speed occurs after the train tail has passed. The peak values vary in approximately the following way:

Distance from platform edge, m	*Peak slipstream gust speed/train speed*
1.0	0.21
1.5	0.15
2.0	0.13

4.2 ICE 2 passing a UK Height Platform

In Figures 3 and 4 again, the averaged slipstream speeds are shown for the ICE 2 passing the station with a UK height platform. The slipstream is strongly characterised by the potential flow velocity peaks as the train's nose and tail pass the measurement location. There is then a small overall speed increase at the two closest measurement positions as the train passes. After the tail speed peak, there is a small rise in speed until a peak value is reached, at about 0.4 seconds, after which there is the decay in the velocity, which again persists for a long period.

The maximum peak slipstream speed is now associated with the passing of the train nose. The peak values vary in approximately the following way and are very much reduced when compared with the values for the German height platform:

Distance from platform edge, m	*Peak slipstream gust speed/train speed*
1.0	0.14
1.5	0.11
2.0	0.09

A comparison between the measurements made on the two platform heights is also possible in Figures 3 and 4. At 2 m from the platform edge, there is general agreement between the measurements as the noses pass (0.15 seconds), as the tails pass at approximately 0.23 seconds, and in the wake for times greater than 0.8 seconds.

At 1 m from the platform edge there is similarity between the measurements made as the noses pass and in the wake region for times greater than 0.4 seconds. There is not such a clear tail potential flow speed peak on the German platform, which contrasts with the measurements on the English height platform.

In all the measurement locations, the peak slipstream air speed measured as the nose of the train passes is lower for the UK height platform case than the German height platform case.

4.3 TGV passing a UK Height Platform

In Figures 5 and 6, the averaged slipstream speeds are shown for the TGV model passing the station with a UK height platform. The slipstream is quite similar to that for the ICE 2 passing the same height platform, described in the last section. However, there is much less evidence of a secondary peak in air speeds at the 2 m position after the train tail passes, (ie at about 0.4 seconds).

The maximum peak slipstream speed is also associated with the passing of the train nose. The peak values vary in the following way and are smaller than the values for the ICE 2:

Distance from platform edge, m	*Peak slipstream gust speed/train speed*
1.0	0.12
1.5	0.09
2.0	0.08

A direct comparison between the measurements made on the two train models is also possible by examining Figures 5 and 6. At 1 m from the platform edge, the slipstream characteristic for each train is quite similar up to the time the tails pass the measurement location. At this point, the measurements are influenced by the train boundary layer.

This is contrasted to the measurements made at 2 m from the platform edge, where again there is similarity between the slipstreams for each train, but there is no evidence of the trains' boundary layers as they pass. Potential flow effects at the trains' noses and tails dominate the slipstream characteristics.

5 Conclusions

Platform height affects the train boundary layer, and hence the structure of the train slipstream and wake around trains. High platforms reduce the train slipstream air speeds very significantly compared with low platforms. The average reduction was 30% for an ICE 2 model passing a UK height platform compared with a German height platform. This general result has also been recently predicted using computational fluid dynamic models in the USA, (Lee, 2003). It is suggested that the higher platform reduce the contribution to the slipstream coming from the bogie roughnesses, leading to the observed effect.

Peak slipstream air speeds occur after the train passes for German height platforms and are associated with the train wake but, in contrast, are associated with the train nose passing for UK height platforms.

The design of the vehicle can favourably affect the strength of slipstream velocity peaks. In the tests passing a UK height platform, the peak slipstream gusts associated with a TGV were on average 14% lower than for the ICE 2.

The MMR is a useful tool for station designers, safety experts and train manufacturers for studying the transient aerodynamic effects of trains in open air.

6 Acknowledgements

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7 References

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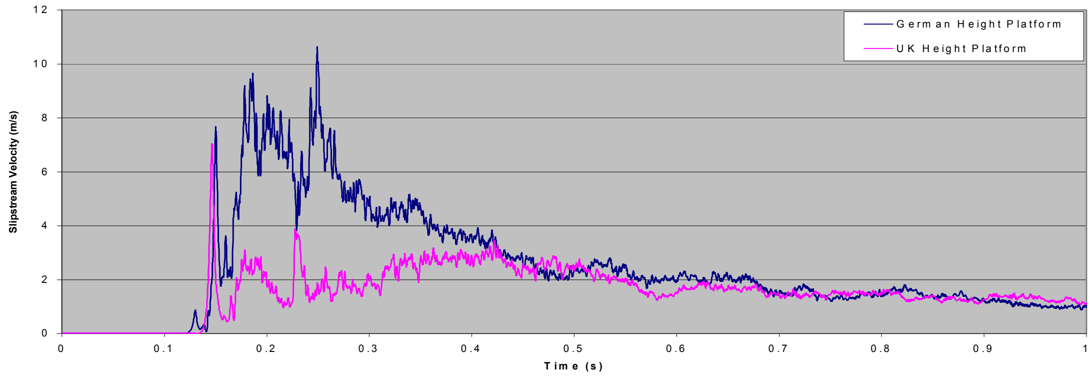
Figure 3 *Comparison of Platform Slipstream Data: Variation of Platform Height*

German Height Platform (0.31m full-scale)	***Measurement position 1.0m***
UK Height Platform (1.0m full-scale)	
ICE 2	Train speed: 50 m/s



Nose / Tail Passing (t < 0.3s)

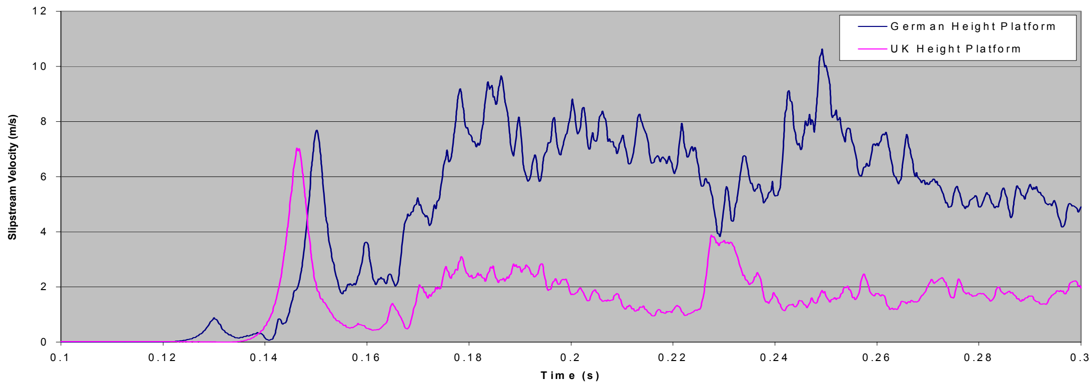
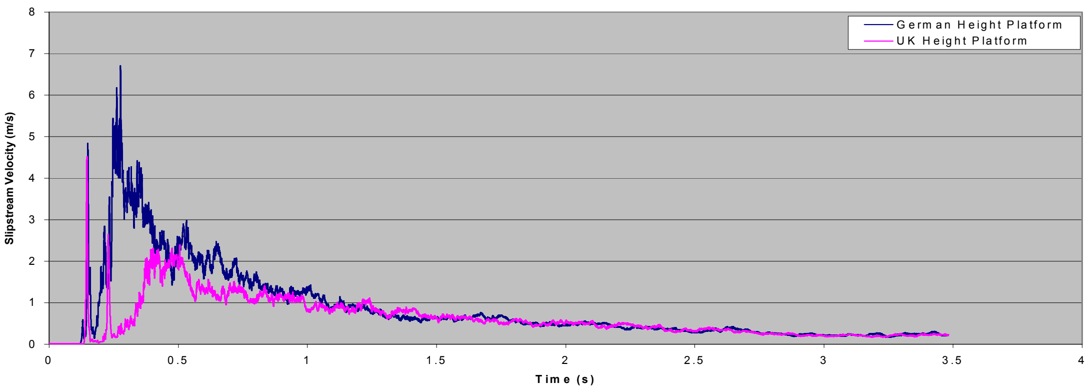


Figure 4 *Comparison of Platform Slipstream Data: Variation of Platform Height*

German Height Platform (0.31m full-scale)	***Measurement position 2.0m***
UK Height Platform (1.0m full-scale)	
ICE 2	Train speed: 50 m/s



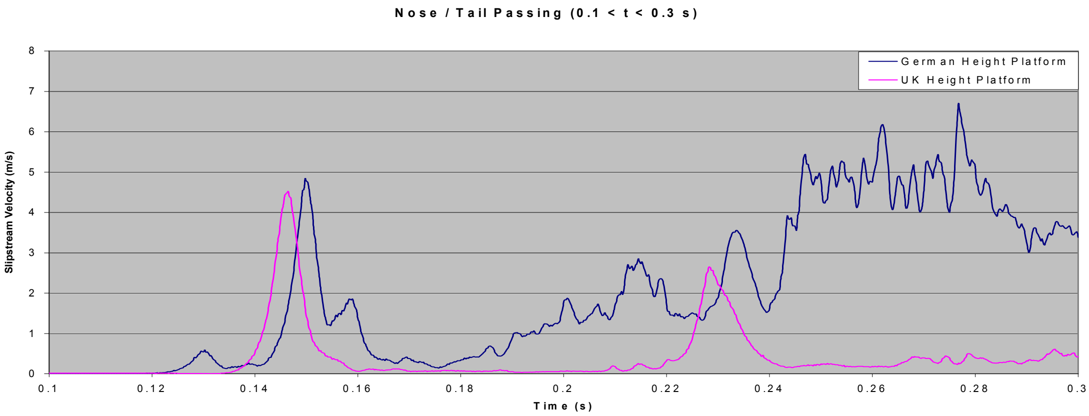
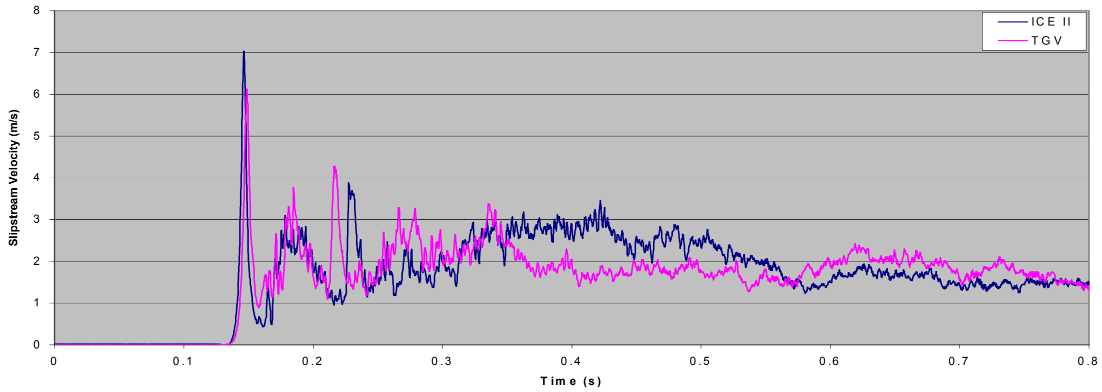


Figure 5 *Comparison of Platform Slipstream Data: Variation of Train Type*

UK Height Platform (1.0m full-scale))	***Measurement position 1.0m***
ICE 2	
TGV	Train speeds: 50 m/s



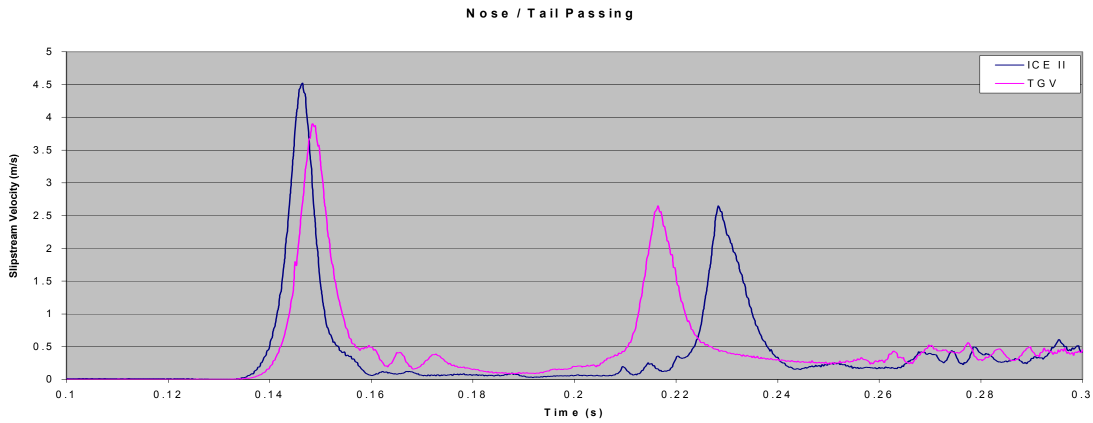
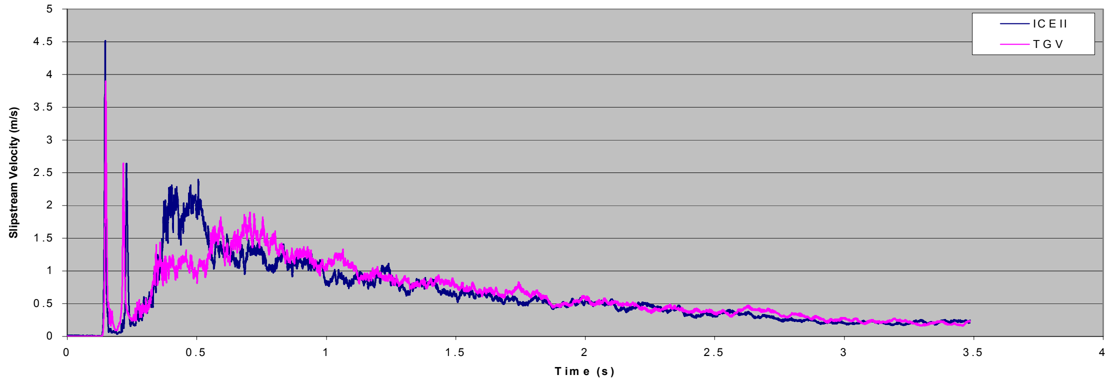


Figure 6 *Comparison of Platform Slipstream Data: Variation of Train Type*

UK Height Platform (1.0m full-scale))	***Measurement position 2.0m***
ICE 2	
TGV	Train speeds: 50 m/s



Nose / Tail Passing

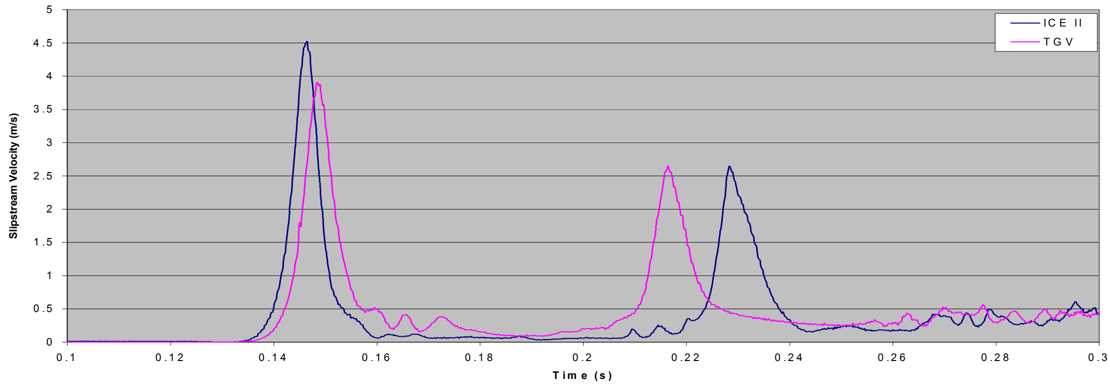


***Figure** 7 Passing Trains Runs: Mid between-tracks measurement position*

ICE 2	50 m/s
TGV	48 m/s