1/25 Scale Moving Model Tests for the TRANSAERO Project

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Summary

AEA Technology Rail have undertaken 1/25 model-scale tests for the TRANSAERO Project using their unique Moving Model Rig. This catapults model trains along a 146 m test track at full-scale train speeds, allowing measurements to be made of the aerodynamic effects generated. Pressures were measured for a shortened model ETR500 train for direct comparison with data gathered during full-scale tests undertaken in Italy. The model was also used to validate numerical simulation predictions carried out for the TRANSAERO Project. Additional model-scale tests were made featuring train nose and track spacing configurations not tested at full-scale. The results have increased the understanding of the importance of these features adding to the knowledge compiled to assist the design of European high speed trains of the future.

Nomenclature

Δp	-	peak to peak pressure change as train nose or tail passes, kPa (§ 9)
ρ	-	air density, $kg.m^{-3}$
V	-	train model speed, $m.s^{-1}$
ΔCp	-	normalised pressure coefficient = $\Delta p/(0.5\rho V^2)$
A_{tr}	-	train cross-sectional area, m^2
s	-	mid-track to mid-track distance, m
e	-	half train width, m

1 Introduction

The Aerodynamics Unit of AEA Technology Rail, (ex BR Research) has a unique moving model facility that allows studies of transient effects on trains to be performed at model-scale. The facility can catapult 1/25 scale train models, either in the open air or through tunnels, at full-scale train speeds. It has been validated against full-scale data [1].

AEA Technology Rail were contracted by the TRANSAERO project to provide model-scale data for the study in Working Party 3, which is summarised in Reference 2. The data was used firstly to confirm the use of the MMR by comparison with full-scale tests performed in Italy as another part of the TRANSAERO project, and then to validate results from numerical simulations taking place at SNCF and by other partners of TRANSAERO. The model tests featured additional configurations to that at full-scale, including two variations to the train nose length and three different track spacings. The results from these configuration tests have increased the understanding of the importance of these features and adds to the knowledge database which has been compiled within TRANSAERO to assist the design of future European high speed train systems.

2 Moving Model Facility

The Moving Model Rig (MMR) at AEA Technology Rail was capable at that time of testing 1/25 scale models of railway rolling stock at speeds of up to 250 km/h. (It has since been upgraded to 277 km/h). The facility has a track length of 146 m with a 46 m test section in the centre where the model will coast at near-constant speed in the open air. Sections of tunnel may be mounted over the test section and it is possible to simulate tunnels up to 45 m (model-scale) in length. The model is propelled by a complex rubber bungee system and braked using a mechanical deformation braking device.

The MMR is unique in its ability to propel realistic model trains at high velocities, thus achieving Mach Number similarity for the majority of full-scale conditions. Experiments performed on the MMR simulate the transient forces and pressures generated by a train on its surroundings. These transient phenomena cannot be modelled in a wind tunnel. Similarly, the MMR is unique in its ability to experimentally model the pressure waves created by the entry of a realistic train into a tunnel. These waves propagate at sonic speed through the tunnel and are reflected by the tunnel openings and train causing a complex wave pattern through which the train has to pass.

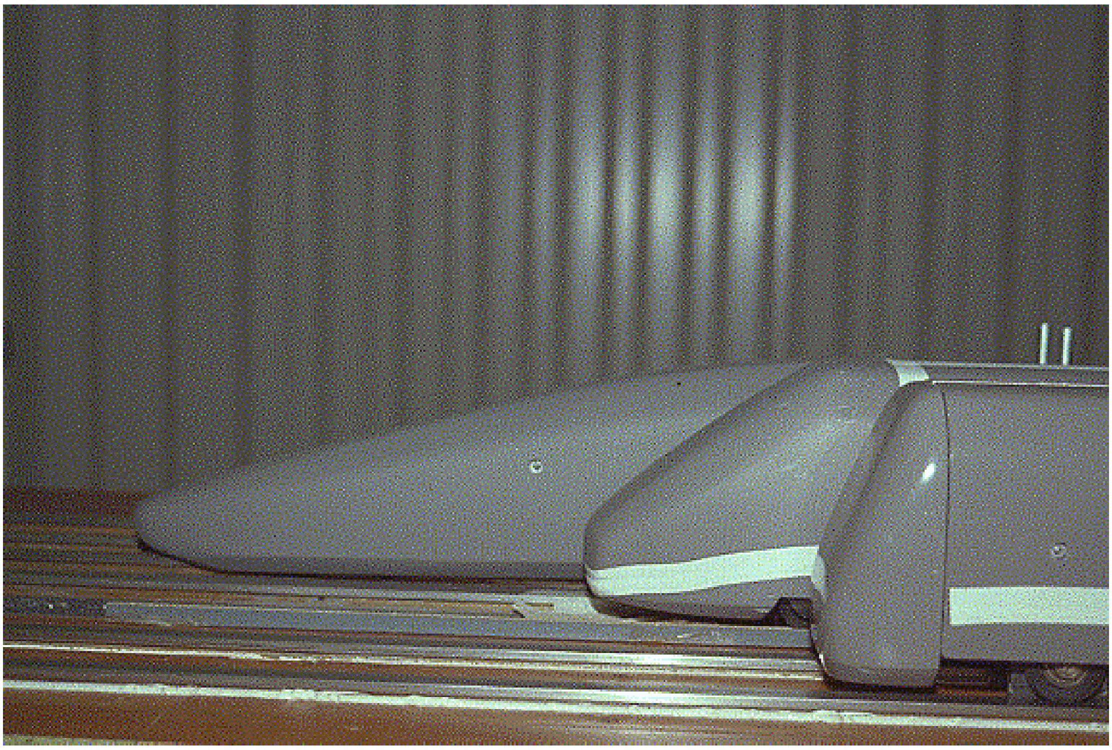
Pressures experienced on the surface of the train models are measured using miniature transducers mounted directly behind tappings on the skin of the model. This arrangement allows the accurate measurement of frequencies of 1000 Hz without the problem of attenuation caused by a tubing system. Due to the fact that 1/25 scale models are being fired at actual train velocities, a factor of 25 is introduced into the scaling of time. For this reason, high frequency data acquisition is necessary but is only needed for the 1-2 second portion of the journey in which the model is moving over the test section of the track.

3 Modelling Detail

The model tests were all performed at 1/25 scale. To maximise the configurations possible, the train passings were simulated by firing a moving model past a stationary model. The pressure tappings were located only on the stationary model and this simplified and accelerated the test process.

The model for the moving high speed train was built from scaled drawings of the Italian ETR500 used in the full-scale test and was identical in nose shape and cross-section to that used by SNCF and DLR in their numerical investigations. The model comprised a loco + two coaches + loco configuration and was thus a shortened version of the nine coach train used at full-scale. The total length of the model with the standard ETR500 nose, (length = 0.176 m) was 3.74 m. The forward end of the ETR500 model could be fitted with either of two noses as well as the standard configuration. One of these was a shortened version of the ETR500 nose where the length dimensions had been decreased by a factor of 3 for the same corresponding height dimensions. The other nose was an elongated version of the ETR500 nose where all the length dimensions had been increased by a factor of 3.

Two static models were built. One was a replica of an Italian freight Loco E652 with three Hbbin306 wagons and had a total length of 2.572 m. The second static model was a shortened copy of the ETR500 train and was identical to the moving model. Both of these train types were used in the full-scale tests, although the full-scale trains featured additional coaches and wagons and hence were longer.



Photograph 1 View of the three ETR500 noses tested

A replica of the first 751 m, (30.02 m model-scale), of the Italian Terranuova la Ville tunnel was constructed and fitted over the test section of the MMR. The tunnel was fitted so that the fast track of the MMR passed through the tunnel on one side, leaving space for the stationary model to be mounted on the other. The model tunnel was fitted with two '½ Penne Pasta' type portals of the type seen on the North entrance to the Terranuova la Ville tunnel. These portals extended for a further 0.737 m beyond the basic tunnel. The beginning or end of the tunnel was defined to correspond to the point at which the portal becomes a continuous part of the tunnel. The portal at the beginning of the tunnel featured a simplified representation of a hillside extending a distance of 0.1 m from the portal.

For the open air tests, the stationary models were positioned at the side of the moving model track using supporting arms, which could be adjusted to give variable track spacing.

4 Instrumentation

Pressure transducers were situated on the static model adjacent to the moving model and also at three positions in the tunnel. The transducers were patched to a PC based data acquisition system where they were sampled at 4000 Hz with 1000 Hz anti-aliasing filters. A light beam event detector was situated in the working section of the MMR. The event detector was also patched to the PC and underwent sampling simultaneously with the transducers, thus giving a record of the model's position and (hence) speed.

4.1 Pressure Measurements

The ETR500 static model was instrumented with 11 pressure tappings on its nose, tail and at two cross-sections on the coaches. The static freight model was also instrumented with 11 tappings located at three cross-sections on the centre wagon. The positions corresponded to transducer locations on the wagon used in the full-scale tests.

The tunnel was instrumented with three tappings. Two were 1.73 m from the beginning of the tunnel at heights of 0.1 m on the left hand side and 0.06 m on the right hand side. The third tapping was positioned 3.21 m from the beginning of the tunnel at a height of 0.1 m on the left hand side. Left hand and right hand relate to the perspective of the moving model.

4.2 Event Measurements

One event detector was positioned in the working section of the MMR. It position varied according to whether the tests were in the open air or in the tunnel and with the choice of stationary model.

The moving model was equipped with retro-reflective tape at two locations. The first strip of tape was located close to the model ETR500 nose, the second was located further down the train. The response of the event detectors to the passing of the tape was used to determine the speed of the model. The maximum error in model speed was estimated to be $\pm$0.02 m/s

5 Tunnel Leakage Area

Pressure wave attenuation is very sensitive to any leaks in the model tunnel (and even an actual full size tunnel may have effective leaks due to cavities in the rock and ballast). It was therefore important to eliminate leakage wherever possible and to determine a value of leakage area for the tunnel. A new, advanced technique for tunnel sealing was developed for the TRANSAERO tests. Special attention was paid to sealing the track bed.

The leakage area was determined by sealing the tunnel portals and pressurising the tunnel using a centrifugal fan. Once pressurised, the fan was sealed off, and the resulting pressure decay recorded. The value of leakage area determined from this experiment was 0.0000032 m^2/m.

6 Model Firing Tests

The project began in January 1997 when the ETR500 moving and static models were commissioned. The first tests took place in June 1997 with an extensive set of firings featuring open air passings of the moving model and the ETR500 static model. The stationary freight train model and the tunnel model were commissioned in July 1997 and the open air passings of the moving model and the freight static model took place in November 1997.

The model passing tests inside the tunnel began in December 1997, with the tests series involving the moving model passing the static freight model inside the tunnel and then the tests involving the moving model passing the static ETR500 model inside the tunnel. On completion of these tests a further series of complementary firings were performed where tunnel pressures were measured for varying nose lengths and train speeds with no other model present in the tunnel. These were completed in January 1998.

6.1 ETR500 Open Air Passings

The stationary model was positioned adjacent to the moving model track. Initial firings were used to establish the repeatability of the tests. A total of 59 firings took place using three different model speeds, three configurations of nose length on the moving model and three track spacings.

6.2 Freight Vehicle Open Air Passings

The stationary model was positioned with its nose facing the moving model and adjacent to the moving model track. A total of 7 firings took place at three speeds using the standard ETR500 nose on the moving model and one track spacing.

Photograph 2 ETR model (right) passing stationary freight train model (left) in the open

6.3 ETR500 Tunnel Passings

The stationary model was positioned in the tunnel on a ground board. Initial firings took place to establish that strong waves were present in the tunnel and also to verify the repeatability of the tests. A total of 12 firings took place using three speeds, the three nose lengths and one track spacing.

Unlike the open air passings where the model is moving at near constant speed over the test section of the MMR, the resistance of the tunnel causes the moving model to slow slightly during its transit through the tunnel. The extent to which the deceleration occurs depends on nose geometry, blockage caused by models etc. in the tunnel and the speed of the moving model. An examination of the data indicated a speed loss in the region of the static model of approximately

0.5-3% for the ETR500 entering the empty tunnel. The model speeds were measured as the train entered the tunnel

6.4 Freight Vehicle Tunnel Passings

The stationary model was positioned on the ground board in the tunnel with the nose of the model 0.089 m inside the tunnel portal. A total of 14 firings took place at speeds of approximately 50 m/s using three train nose lengths and three track spacings.

6.5 Empty Tunnel Firings

A total of 9 firings took place through the empty tunnel at three speeds and using the three nose lengths.

7 Validation - Comparison with Full-scale Data.

A brief comparison of the test data with the full-scale data was undertaken. A set of full-scale data was selected which had been sampled on a static ETR500 as it was passed in the open by a 9 coach ETR500 travelling at 181 km/h. This was compared to MMR model data, which was sampled on a static ETR500 model as it was passed by a 4 vehicle ETR500 model travelling at 181.1 km/h.

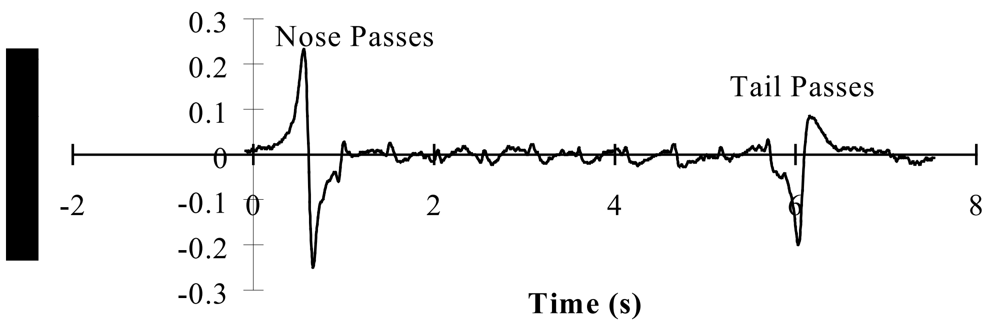


Figure 1 Full-scale data

Figure 1 shows the pressure time history seen at a tapping in the centre of the first coach of the full-scale static train as the moving train passes. Figure 2 shows the data recorded for the same configuration during tests on the MMR. The pressures are shown in units of kiloPascals.

The pressure trace in Figure 2 has been cut after the passing of the first coach and offset along the time axis to account for the reduction in train length by seven coaches. The initial rise and fall in pressure as the nose of the moving vehicle passes the tapping is evident and near-identical in the two traces. This is an important result for the modelling as this peak to peak change in pressure gives a measure of the maximum force fluctuation generated by the moving train on its surroundings.

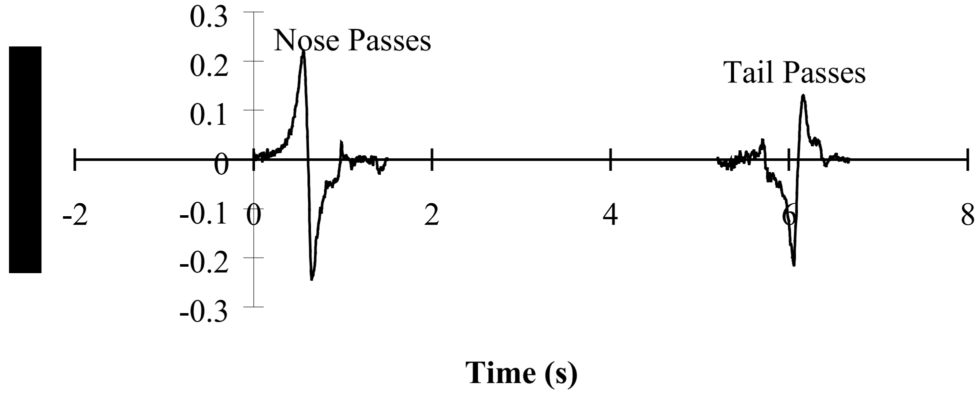


Figure 2 MMR data

Following the time history in Figure 1, the pressure can be seen to fluctuate around zero as the coaches of the full-scale train pass the tapping. There are clear periodic fluctuations and these correspond to the reduced inter-car cross-section between the coaches. Some can be observed at model scale in Figure 2, eg at about 1 second.

The fall and rise in pressure as the tail of the moving train passes the tapping is again simulated at both scales. However this time the model test has slightly over-predicted the peak to peak pressure change. This is could be due to differences introduced into the flow regime because of the shorter train length.

A comparison of the MMR test data with full-scale data was performed using a set of full-scale data which had been sampled at a tapping 80 m from the entrance to the tunnel as a 9 coach ETR500 passed through the Terranuova la Ville Tunnel travelling at 180 km/h. This was compared to MMR model data, which was sampled at an identical position in the empty model scale tunnel as it was passed by a 4 vehicle ETR500 model travelling at 185 km/h.

The solid line on Figure 3 shows the pressure time history at full-scale in the tunnel and the dotted line shows the pressure time history measured on the MMR.

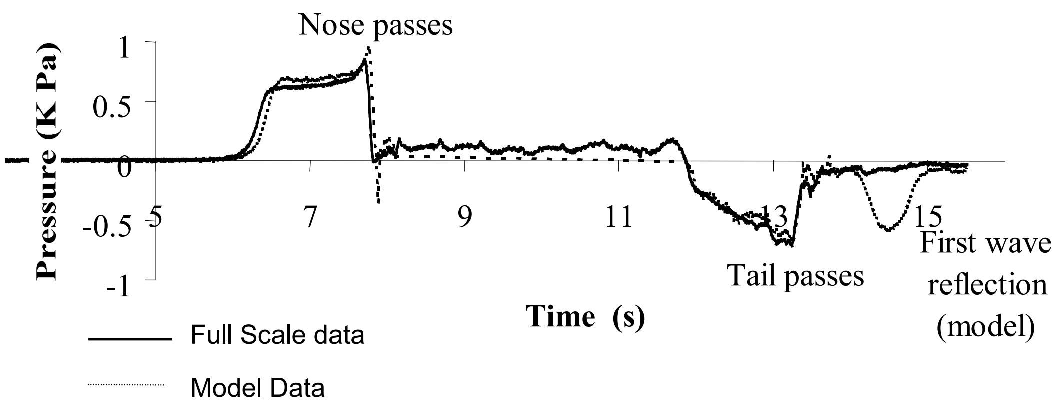


Figure 3 Comparison of full-scale and MMR data in tunnels.

The initial pressure rise on both traces at 6s shows the arrival of the nose entry wave at the measurement position, with the sharp drop in pressures at 8s occurring as the nose of the train passes the measurement position. It can be seen that for all of these features the MMR data describes the full-scale situation well. The slightly larger values of pressure seen at model scale are be ascribed in part to the higher speed of the model. The peaks seen directly before and after the nose passing pressure drop are caused by the localised effect of the bogies. The differences between the MMR and full-scale data are attributed to the fact that in the MMR tests, the model was travelling closer to the tunnel wall, and here localised effects were recorded more strongly.

After the nose has passed the full-scale pressures are almost constant, but show small periodic fluctuations caused by the passing of the 9 coaches. The MMR data has been cut at this point and displaced along the time axis to account for the shorter train length. When the train has passed the pressures become negative as the rarefaction pressure wave caused by the tail entering the tunnel reaches the measuring position. This is quickly followed by the passing of the tail, after which the pressure traces returns to ambient. It can be seen that for both of these features the MMR trace accurately simulates the situation measured at full-scale.

Shortly after the tail passes the measurement position, the MMR pressure shows the effect of the reflection of the nose entry wave from the end of the tunnel. As the model tunnel is much shorter then the full-scale tunnel this effect is not seen in the full-scale trace and after this time comparison between the two traces becomes inappropriate.

It was concluded that the MMR produces an excellent representation of the full-scale situation, both in the open air and in tunnels.

8 Analysis of Open Air Passing Tests

As the nose of the moving model passes the static model a transient pulse, comprising firstly a positive then a negative pressure is seen in the time histories. In the following analysis, the peak to peak value of this pressure pulse is used to characterise the train passing event and it is used to indicate the influence of model speed, nose geometry and track spacing.

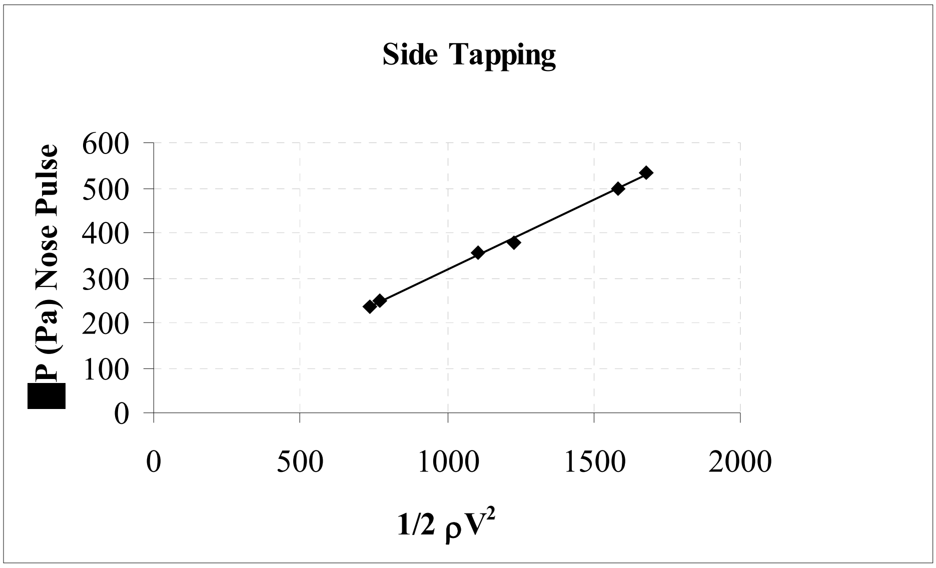


Figure 4 Nose passing pressure change at the tapping on the side of the stationary freight model in the open.

8.1 Effect of speed

Figure 4 shows the peak to peak pressure change, (Δp), at a tapping on the side of the central freight wagon as the nose of the moving model passes. The data represents moving model firings at six different velocities and Δp has been plotted against the train dynamic head, $\rho V^2/2$, where ρ is the density of air and V the speed of the moving model. It can be seen that, within experimental scatter, there is a linear relationship between the amplitude of the pressure fluctuation and the speed squared. This enables the use of a normalised pressure coefficient, ΔCp, in the following analysis.

$$\Delta Cp = 2\Delta p / (\rho V^2) \qquad (1)$$

8.2 Effect of Nose Geometry and Track Spacing

Figure 5 considers the passing pulse inflicted by the nose of the moving model on the tapping on the nose of the stationary model. The Figure displays normalised pressure data from all the open air ETR500 passings, plotted against the non-dimensional parameter $A_{tr}/(s-e)^2$, where A is the train cross-sectional area, s is the mid-track to mid-track distance and e is the half-train width. This parameter was first proposed by Gaillard[(3)].

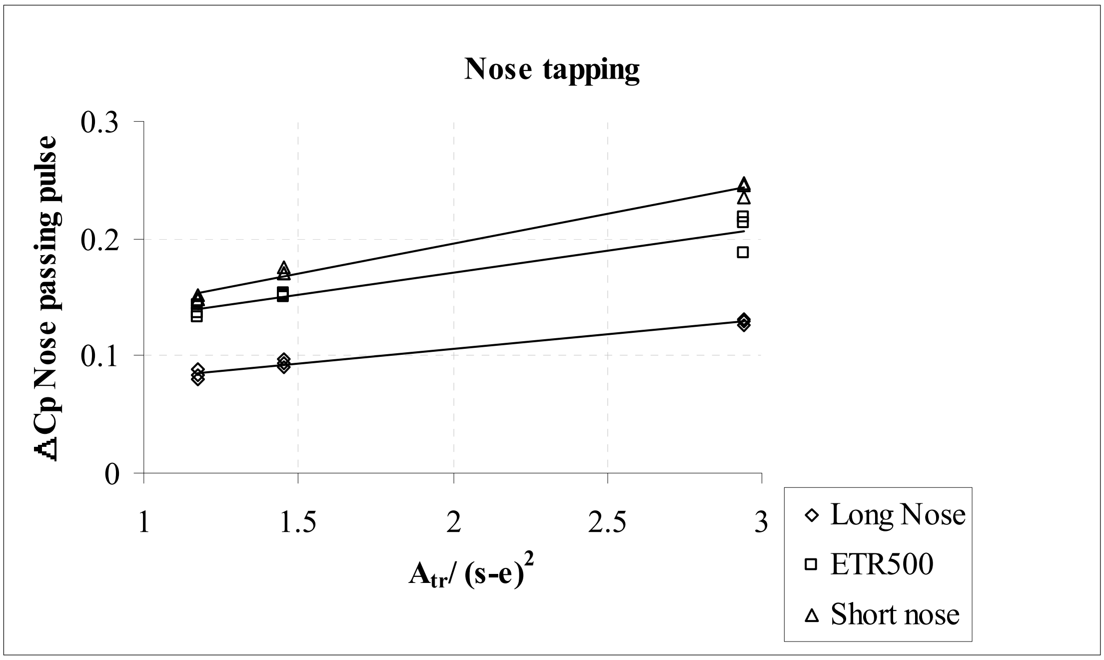


Figure 5 Effect of nose passing the tapping on the nose of the stationary ETR500 model in the open.

It can be seen that the normalised pressure pulse exerted by the nose of the moving model varies linearly with $A_{tr}/(s-e)^2$.

Increasing the nose length dramatically reduces the pressure pulse with the greatest reduction occurring for the long nose.

Figures 6 and 7 show the same information for taps on the centre of the first cross-section and on the tail, of the stationary model. The tapping on the side sees much greater pressures than those at the nose or tail of the stationary train. This reflects the fact that it is much closer to the moving model and is in a region of greater blockage. The trends with track spacing and nose length for Figure 5 are also apparent in Figure 6 and 7. Figure 6 shows a particular reduction in pressure pulse for the long nose and also indicates that the pressure pulse is less affected by the three different track spacings for this longer nose.

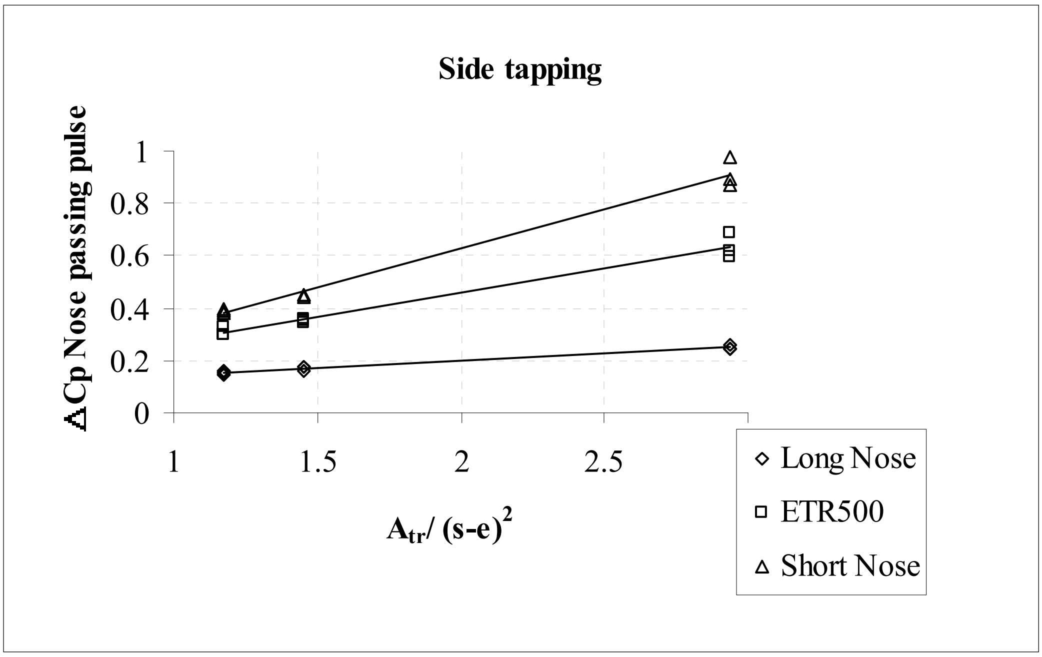


Figure 6 Effect of nose passing the tapping on the side of the stationary ETR500 in the open.

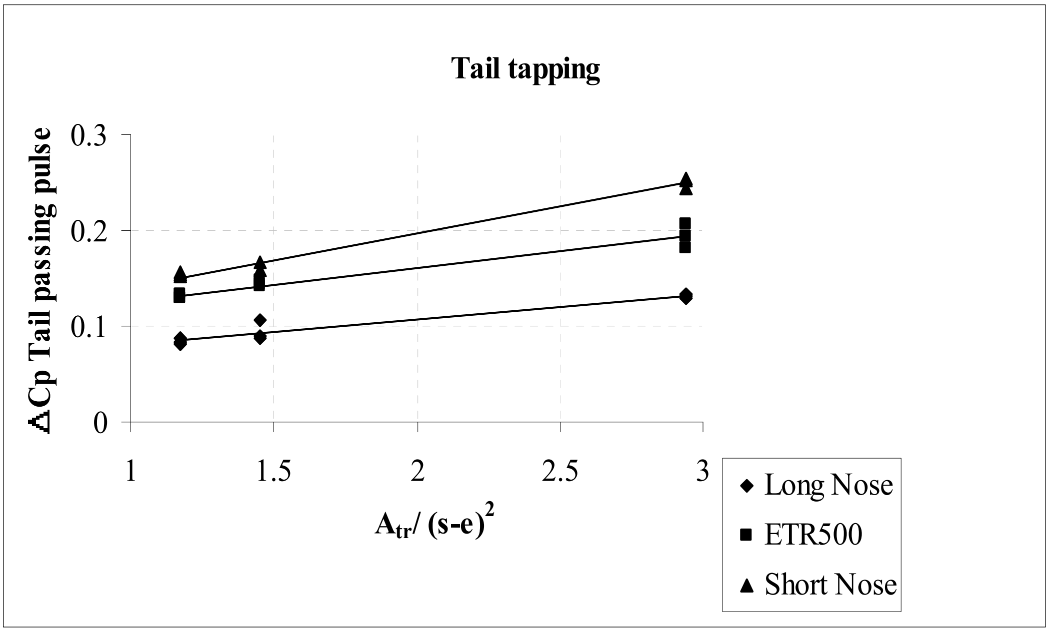


Figure 7 Effect of nose passing the tapping on the tail of the stationary ETR500 in the open.

9 Analysis of Tunnel Passing Tests

The pressure time histories measured inside the tunnel are complicated by the presence of pressure waves generated by the entrance of the moving model and reflecting from the tunnel portals, but which were not of interest here.

The static model was positioned near to the tunnel entrance in order to avoid reflected waves occurring when the model passings took place. Using wave diagrams calculated for the experimental set up it is possible to conclude that the nose passing event is clear of the reflected waves and can be identified as a rapid drop in pressure occurring after the initial rise of the nose entry wave. During the following analysis the amplitude of this pressure drop is used to characterise the pressures exerted by the nose passing event and is used to examine the effect of nose geometry, track spacing and model speed.

9.1 Effect of Speed

Figure 8 shows the pressure drop at a tapping on the cross-section of the ETR500 static model as the nose of the model passes. Firings are available at only three speeds, however it is obvious that for all three nose configurations of the moving model the pressure varies linearly with the speed squared of the moving model.
This finding enables the use of the normalised pressure coefficient (see Section 8.1) again in the following analysis. It also indicates that in future experimental simulations, where only the passing event is examined, the simulation of actual train speeds is not important.

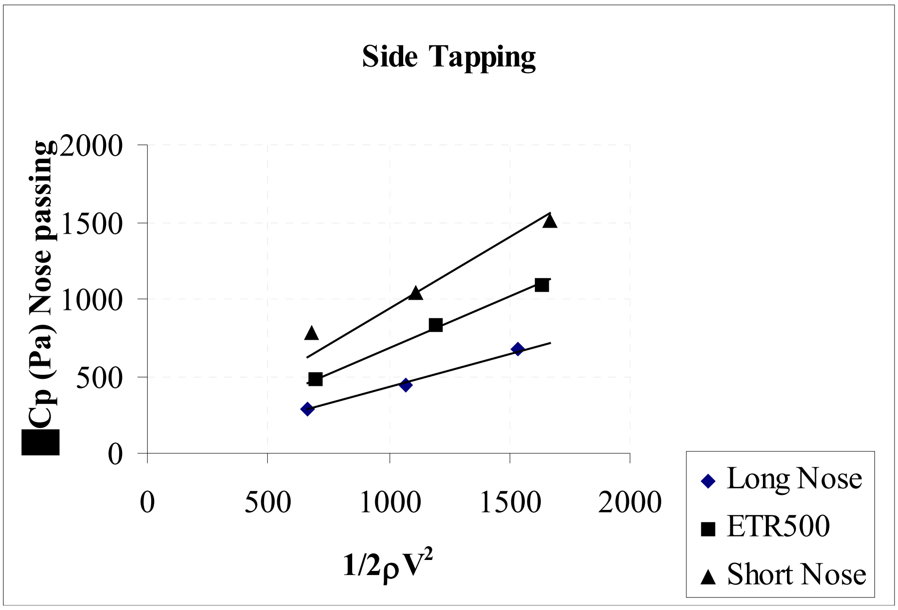


Figure 8 Nose passing pressure drop at the tapping on the side of the ETR500 in the tunnel.

9.2 Effect of Nose Geometry and Track Spacing

Figure 9 considers the pressure drop generated by the nose of the moving model on a tapping on the cross-section of the stationary freight model, here plotted against track spacing.

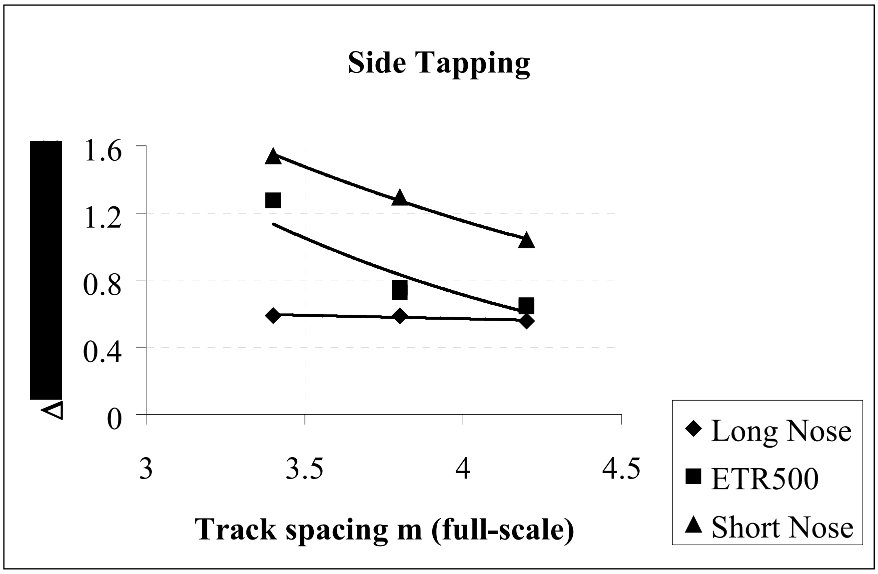


Figure 9 Effect of nose passing the tapping on the side of the stationary Freight model in the tunnel.

It can be seen that an increase in track spacing reduces the pressure pulse exerted by the nose of the moving model for all the noses. The relationship between track spacing and ΔCp is not linear. The long nose appears to be even less sensitive to the track spacing than was seen in the open air passings.

10 Conclusion

A test series has been conducted on the MMR for the TRANSAERO Project. Over 60 firings took place both in the open air and in a tunnel.

A brief validation was conducted using full-scale open air and tunnel data. It was found that the MMR data gave an excellent representation of the full-scale situation.

A simple analysis was also undertaken. Data from each firing was represented in terms of the peak to peak pressure change caused by the passing of the moving model nose. This parameter was then analysed for trends with model speed, track spacing and nose length.

It was found that both in the tunnel and in the open air, the pressures varied linearly with the square of the speed. This confirmed the suitability of representing nose passing effects by a non-dimensional coefficient, as is current AEA Technology Rail practise.

Increasing the length of the nose of the model had a dramatic effect in reducing the pressures inflicted by the nose on its environment.

Increasing track spacing gave a decrease in pressures. The relationship between pressure and track spacing was not linear and varied for nose length. The long nose was less sensitive to track spacing, particularly in the tunnel where the track spacing had remarkably little effect on the pressure experienced as the long nose passed.

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