Model rig measurements for SNCF new tunnel portal designs

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Tests were undertaken using a moving model rig to determine the effect of different tunnel portal extensions on the initial wave generated by the entry of model trains into the tunnel. Two separate portal designs and a plain portal were tested. Measurements were made of the pressures in the tunnel as the train entered and the relationships determined between the train nose design, the train speed and the design of the portal.

1 Introduction

The SNCF Rolling Stock & Traction Department, in association with the SNCF Research Department, (hereinafter designated as SNCF), have undertaken parametric studies of the initial pressure variation due to the entry of a train into a tunnel with changes of train velocity, train type and train/tunnel cross-section.

The objectives of this project were:

- The acquisition of general experimental information (pressure values) concerning the aerodynamic phenomena involved and their effects on rolling stock, with a 1:25 scale model train passing through a tunnel. This information will be compared with the results of full-scale tests and the result of numerical simulations.
- To determine the relationships between the pressure distribution recorded during the entering of the train and the speed of the train, the geometrical design of the front of the train, the geometrical design of the portals of the tunnel and the blockage ratio (train cross-sectional divided by the tunnel cross-sectional area)
- The validation of previous studies using straightforward software tools devoted to facilitate the pre-sizing and the specification of the train/infrastructure systems.
- To use the knowledge and the experience gained for the preparation of charts of European train inter-working (STI) and the establishment of formal criteria for aural safety and pressure comfort as well as functional specifications in terms of sealing of rolling stock.

Extensive use has been made of tests with full sized trains to obtain an understanding of the air flows generated in tunnels and for validating unsteady flow prediction methods. Compared with simulation with reduced scaled models, full-scale tests have the important advantage of being free of Reynolds number effects. Nevertheless, they have numerous disadvantages; they are labour-intensive and expensive to implement and organise. They are also restricted to train and tunnel geometries that already exist.

Thus, it was decided to perform the SNCF tests using 1/25th scale models on the Moving Model Rig facility belonging to AEA Technology Rail.

2 The Physical Phenomena

When a train enters a tunnel, compression and expansion waves of various intensities are generated by the head and tail. If sufficiently strong, such waves can create adverse effects such as aural discomfort of passengers and rapidly changing forces on the train and on the tunnel structures. An example is given in Figure 1 of the pressure time history at a fixed point in the Vouvray Tunnel created by a TGV trainset.

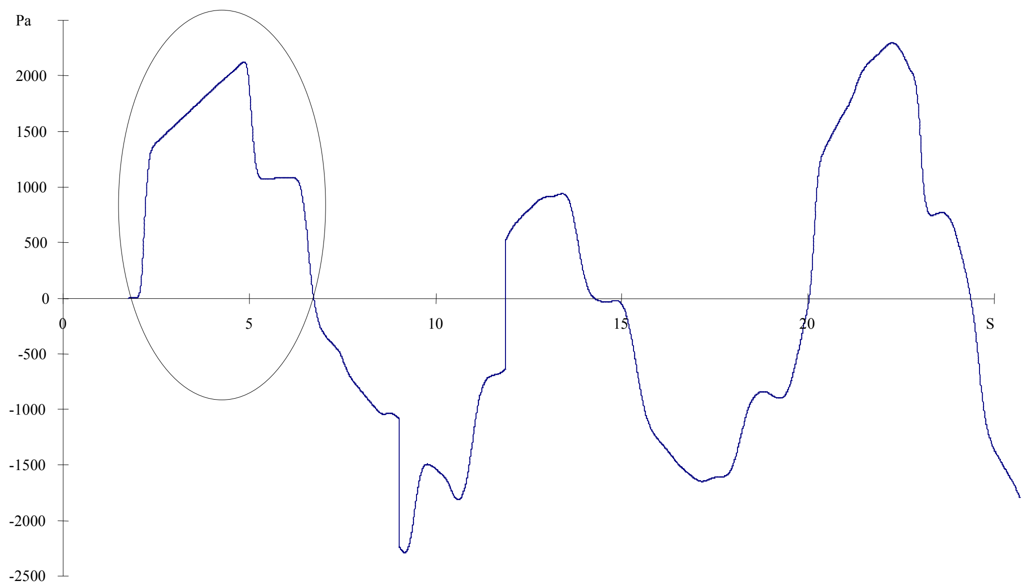


Figure 1 Time history of relative pressure at a point in the tunnel

Circled in Figure 1 and shown in greater detail in Figure 2, are the pressure characteristics of train entry.

As the train passes into the tunnel, a sudden rise in pressure occurs due to the constraining effect of the tunnel walls which is transmitted along the tunnel at the speed of sound. This is followed by a further rise in pressure due to the effect of frictional forces on the side of the train and the tunnel walls. This rise in pressure continues until the tail of the train enters. A tail wave then propagates over the train causing a sudden fall in pressure. (The above behaviour is only applicable if the tail wave reaches the nose of the train prior to the arrival of the reflection of the nose entry wave).

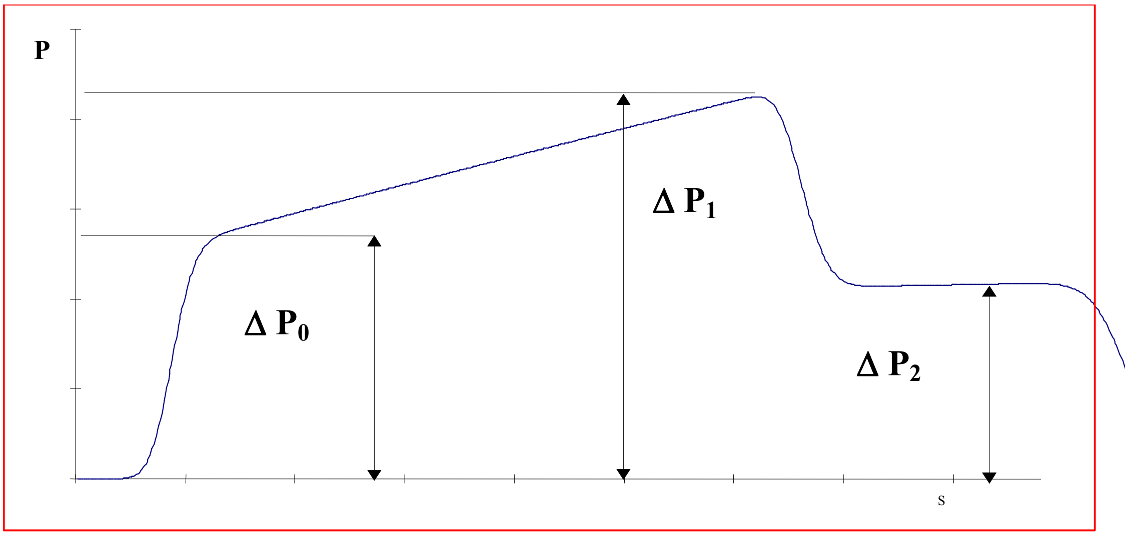


Figure 2 Time history of train entry relative pressure at a point in the tunnel.

Then, the pressure time history of a train entering a tunnel is characterized by the following pressure changes:

- ΔP0, which is due to the entry of the head,
- ΔP1-ΔP0, which is due to the entry of the rest of the train
- ΔP1-ΔP2, which is due to the entry of the tail

For a given reference tunnel, and knowing its characteristics, the variations of pressure ΔP0, ΔP1 and ΔP2 will only depend on the length and on the section of the train, its speed of operation, the form of its nose, the form of its tail and its surface quality (or its roughness).

3 PRESSURE COMFORT CRITERION

The main parameters for aural pressure comfort are the total variation of pressure, ΔP, anywhere on board the train and the gradient of pressure, dP/dt. Previous studies of these two quantities and people's subjective reaction to changes in them have allowed the determination of iso-discomfort percentage curves. These curves quantify the percentage of people disturbed or discomforted by changes in ΔP and in dP/dt.

Figure 3 gives the range of (ΔP, dP/dt) pairs for the 10% and 20% iso-discomfort curves. Positive ΔP values are for increasing pressure changes and vice versa. The area shown shaded indicates the range of (ΔP, dP/dt) pairs for which the number of people discomforted is less than 20%.

Inspection of Figure 3 shows that there are numerous (ΔP, dP/dt) pairs on this iso-discomfort curve, all of which will ensure no more than 20% of people will feel discomfort. The SNCF chosen reference point is ΔP = 1000 Pa with dP/dt = 500 Pa/s, which defines the comfort limits for the occupants of French trains.

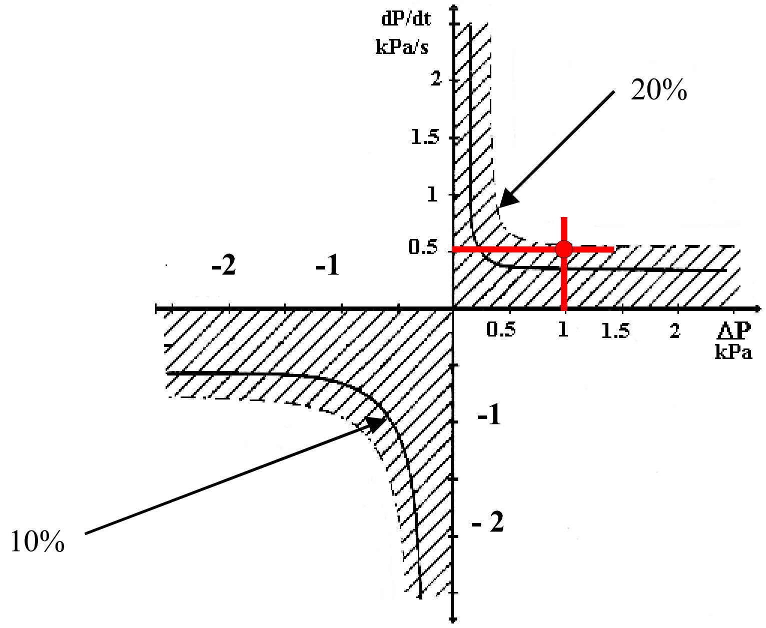


Figure 3 Region where the percentage of people discomforted is less than or equal to 20%

4 THE MOVING MODEL RIG

The Moving Model Rig (MMR) of AEA Technology Rail is a facility that was designed primarily for the measurement of train generated tunnel pressures, although is equally used now for open air studies. The MMR has three tracks, along which 1/25 scale model trains can be projected at full-scale speeds up to 310 km/h. It is 150 m in length, with a central test section of 46 m. The first 50 m of the tracks are used to accelerate the train models up to the required testing speed using a system of rubber bungees. After leaving the test section the models are decelerated using a mechanical deformation braking system. A full description of the MMR is given in Reference 1.

Model tunnels can be placed on the central test section. As full-scale test speeds are used, Mach number similarity of aerodynamic phenomena is achieved. This is particularly important for the study of pressure wave phenomena in tunnels. Reynolds number similarity is achieved within the scale factor of 25 on the basis of AEA Technology Rail's testing with static models in wind tunnels. The chief advantage of the MMR over a conventional wind tunnel is the ability to replicate the rapid changes of air velocity and pressure caused by a moving model.

The model measurements made in the MMR have been validated against full-scale measurements as described in References 2 and 3.

5 MODELS

5.1 Tunnel Models

A model of a section of the French Vouvray Tunnel was used for the tests. This had been built previously for model tests in the EC co-funded project, RAPIDE(4). The (model) tunnel is 751 m long with a cross-sectional area of 71.88 m2, (dimensions all full-scale). The model was initially fitted with a blanking board to simply represent the mountain face into which the actual tunnel is driven (see Figure 4).

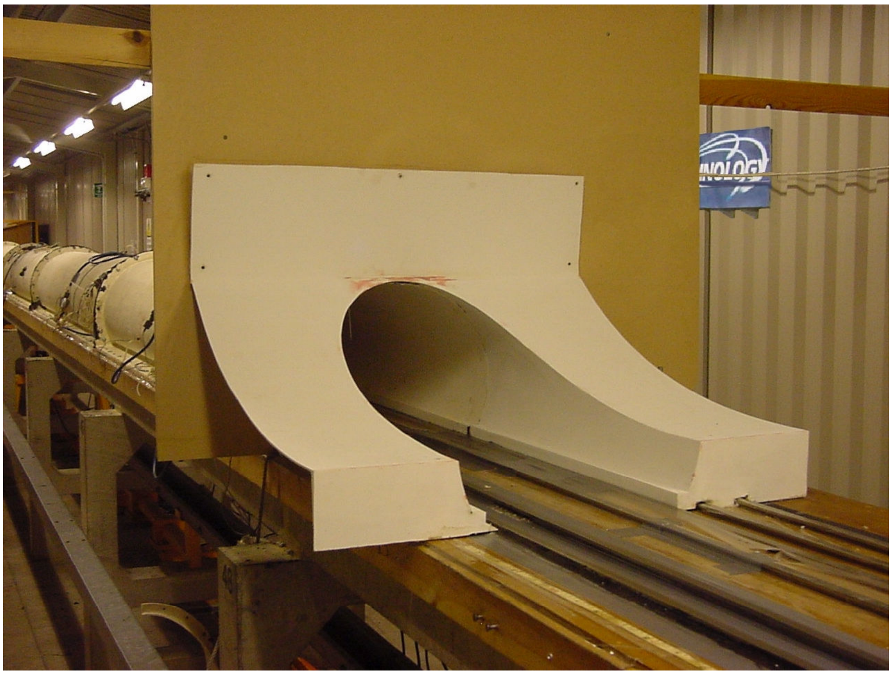


FIGURE 4 'Half penne pasta' portal mounted on the tunnel with mountain face representation

The tunnel was then fitted with two portal extension designs. These are shown in Figures 4 and 5.

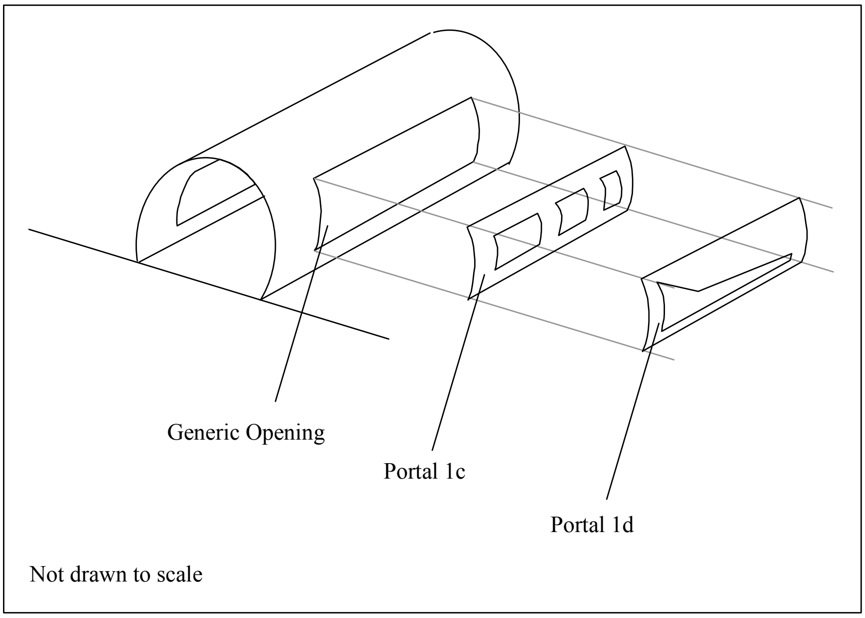


FIGURE 5 Diagram of generic portal with 'side windows'

The first is the so-called 'half penne pasta' design because of its resemblance to penne pasta, and is a tunnel portal entrance design common in Europe. This portal was fitted at both ends of the model tunnel, extending it by 18.43 m at each end.

The second was a generic cylindrical portal of 20 m length, which had a large rectangular cut-out on each side. Two inserts could be place in the rectangular window, thus modifying the shape of the opening into the portal sides. The first had three specially designed smaller holes in, whilst the second had a continuous slot opening.

5.2 Train Models

The basic train consists of a main chassis, a central spine and a trailing chassis. A shell representation of the train model is built around these components, (see Figure 6). A primary objective is to minimise the weight of the train model in order to achieve the target speeds. For this reason, the train models consisted of only a leading power car, two intermediate vehicles and a trailer power car.

The trains tested were:-

- the French TGV Réseau (TGV R)
- the French TGV Duplex.

These are shown in Figure 7.

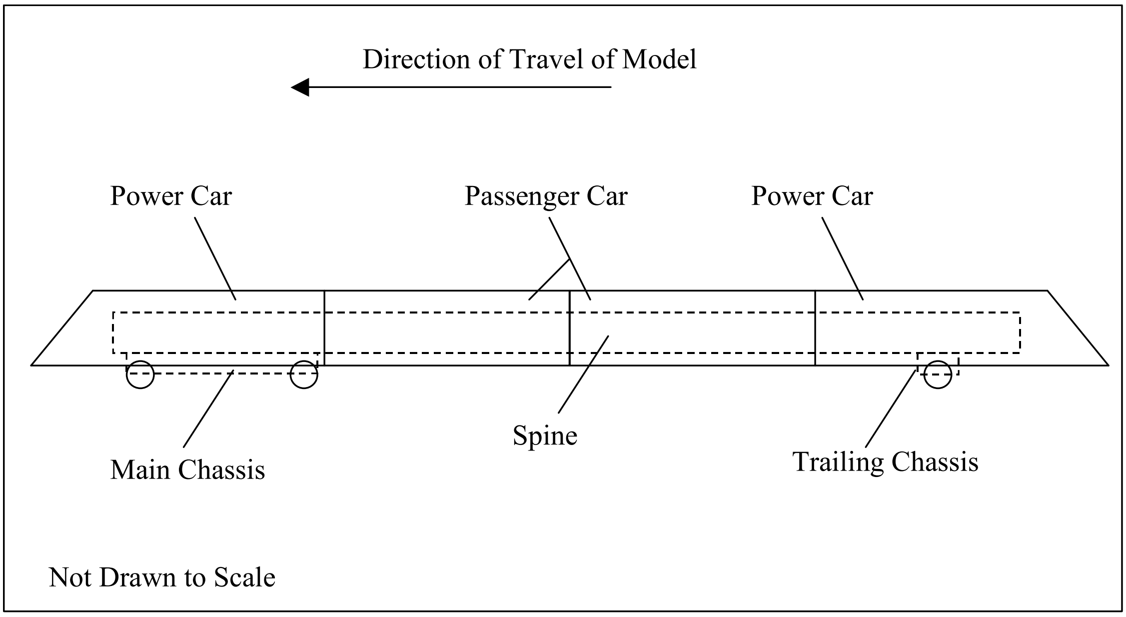


FIGURE 6 Schematic representation of the train model

The lighter model was the TGV Réseau, weighing 5.61 kg, which was made from a new material. The new material is lighter, more flexible and less prone to fatigue damage than glass fibre reinforced plastic, which is the standard construction material.

TGV Réseau model

TGV Duplex model

FIGURE 7 Train models

5 INSTRUMENTATION

Ten locations in the tunnel were fitted with Endevco 8510b-2 pressure transducers calibrated over the range ±4 kPa, (see Figure 8). Data was collected by sampling to a PC at 4000 Hz with 1000 Hz anti-aliaising filters.

Three light beam event detectors were situated in the tunnel. Retro-reflective tape was stuck to the train models which activated the event detectors as the tape strips passed them. These enabled the train speed and position to be evaluated for each test run.

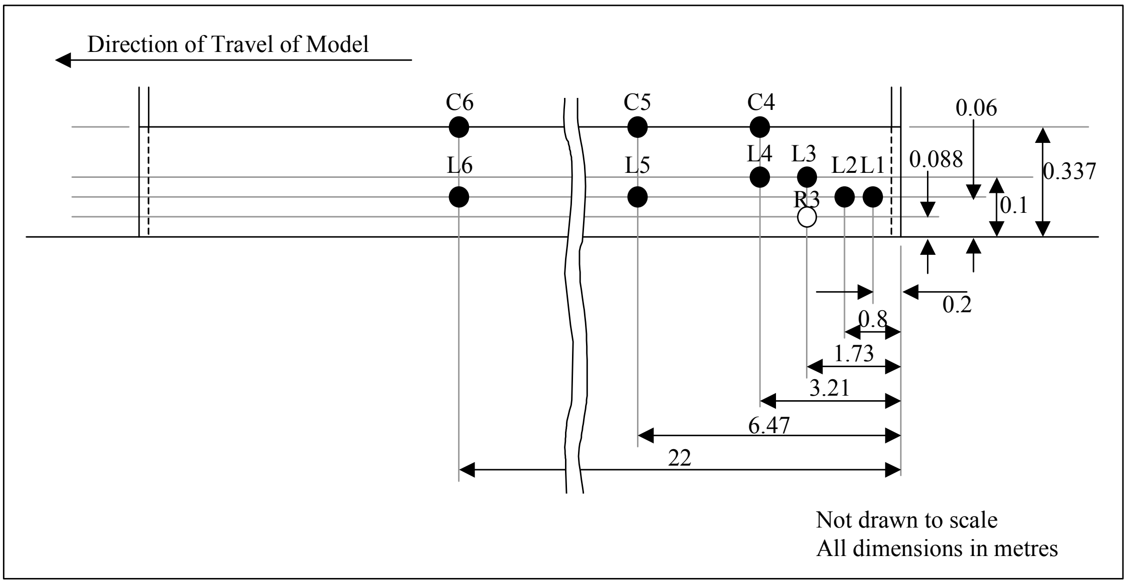


FIGURE 8 Schematic diagram of pressure tapping arrangement (side elevation, dimensions at model scale)

6 EXPERIMENTAL PROGRAMME

6.1 Tunnel Leakage

Pressure wave attenuation is very sensitive to any leaks in the tunnel. It is thus very important to eliminate as many leakage paths as possible from the tunnel model to atmosphere. Special care was taken to seal the track bed prior to installation of the tunnel model sections. Each tunnel section was then bolted together and sealed with sealant paste to effect an airtight seal.

The leakage area of the tunnel was found by sealing the tunnel portals and over-pressurising the air in the tunnel to 2 kPa above atmospheric. The resulting pressure decay with time was then monitored and recorded. It was then possible to calculate the leakage area of the tunnel, which was found to be 3.83 x 10-5 m2/m (model scale).

6.2 Test Runs

There were a large number of runs for the four different tunnel portals (plain, 'half penne pasta', three windows', 'continuous window') and trains configurations. The train speeds varied between 150 km/h to 270 km/h.

7 ANALYSIS

The pressure data was further low-pass filtered with a linear filter having an equivalent cut-off frequency of 10 Hz to remove excess noise. The pressure gradient was then calculated on the basis of the filtered signal following a first-order centred finite difference scheme.
The analysis deals with confirming with the degree to which the train entry pressure signature can be modelled and determines the influence of tunnel extensions on it and on the pressure gradient.

The train entry signature of Figure 9 is analysed in terms of ΔP0 as defined in Figure 2.

The ΔP0 term depends on the head of the train. It is deduced from the intersection of the two mean slopes of the entrance train signal. Figure 9 shows the pressure measured at two train speeds and the determination of the ΔP0 term in each case. The estimated error for the lower speed is approximately 10 Pa and for higher speed is 50 Pa. These values represent a maximum of error of 3% in the ΔP0 term for all the runs.

Figure 10 shows the pressure changes for a TGV Duplex at a tapping on the side of the tunnel without portal extensions. The data represents moving model firings at five different velocities for TGV Duplex and TGV Réseau from 180km/h to 270 km/h. The ΔP0 term is plotted against the train dynamic head, ½ρV2, where ρ is the density of the air and V is the speed of the moving model. It can be seen that, within the experimental scatter, there is a linear relationship between the amplitude of the pressure fluctuation and the square of the speed. This allows the use of a normalised pressure coefficient in the following analysis :

$$Cp = \frac{\Delta P_0}{0.5 \rho V^2}$$

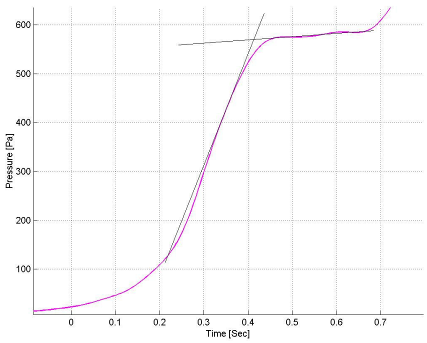
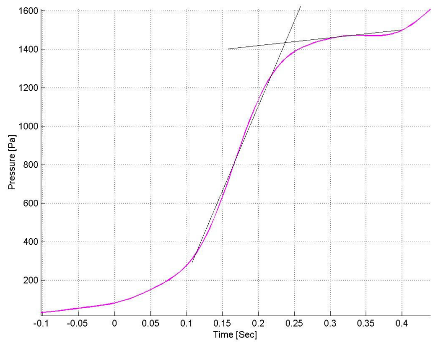
180 km/h	270 km/h
	

Figure 9 Determination of the ΔP0 term for two train speeds from pressure signal vs full scale time

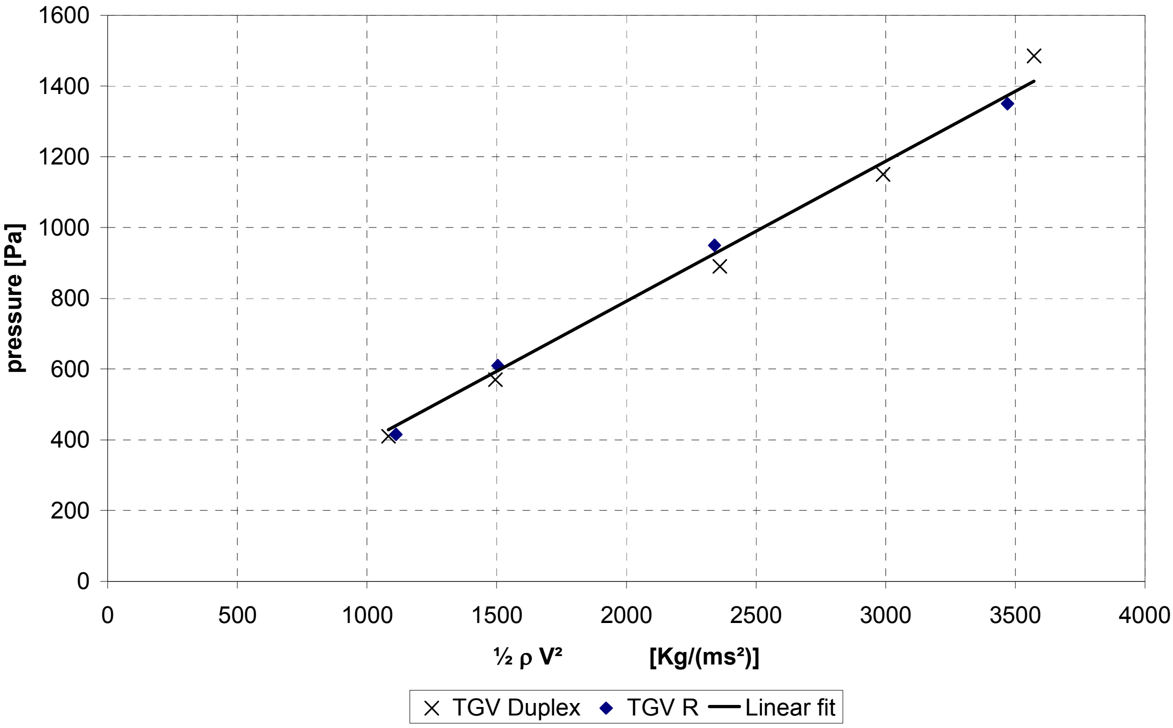


Figure 10 Effect of train speed on the ΔP0 term for TGV Réseau and TGV Duplex

Figures 11 and 12 present the CP variation due to the entering of TGV Réseau and TGV Duplex for the tunnel with different extensions. The results clearly indicate that there is no significant influence of the extensions on the CP term.

Since previous SNCF analysis indicated that the amplitude of the initial pressure wave has a low sensitivity to the form of the tunnel ends, the focus of this study is directed to the wavefront pressure gradient produced by the entry of the nose of the train. Figure 13 gives an example of time history of (pressure and gradient pressure) versus time for a TGV Duplex at 270 km/h. The value of the pressure gradient seems very high. However, the wave front pressure gradient is reached for lower pressure than the $\Delta P0$ value. Moreover, internal pressure of the train is lower than external pressure. **So the SNCF criterion is not exceeded while the train enters in a tunnel.** However, there is no simple relationship between this gradient and those seen by the passengers.

Figures 14 and 15 show the effect on the pressure gradient of the half penne pasta, the three hole cylindrical and the gradual slot cylindrical portal extensions. The speed ranged from 180 km/h up to 280 km/h. Also shown is the line of best fit to the data for the tunnel without extensions.

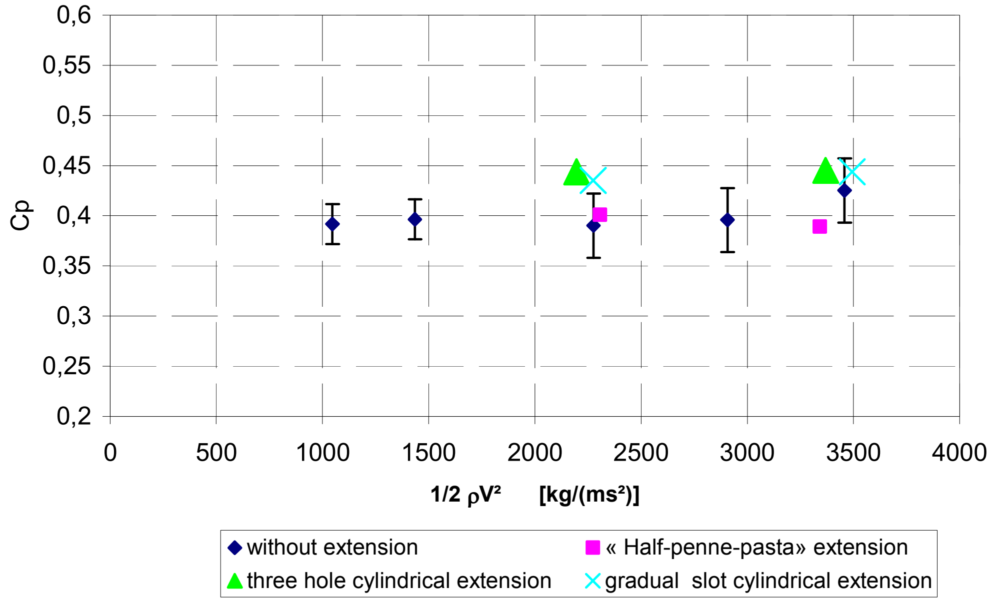


Figure 11 Cp Variation for TGV Duplex

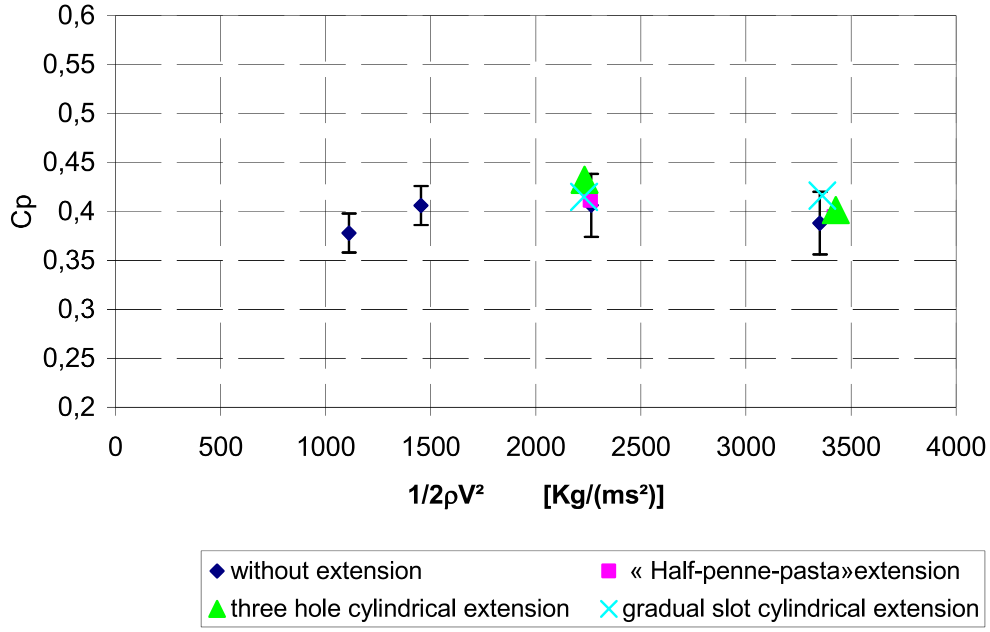


Figure 12 Cp Variation for TGV Réseau

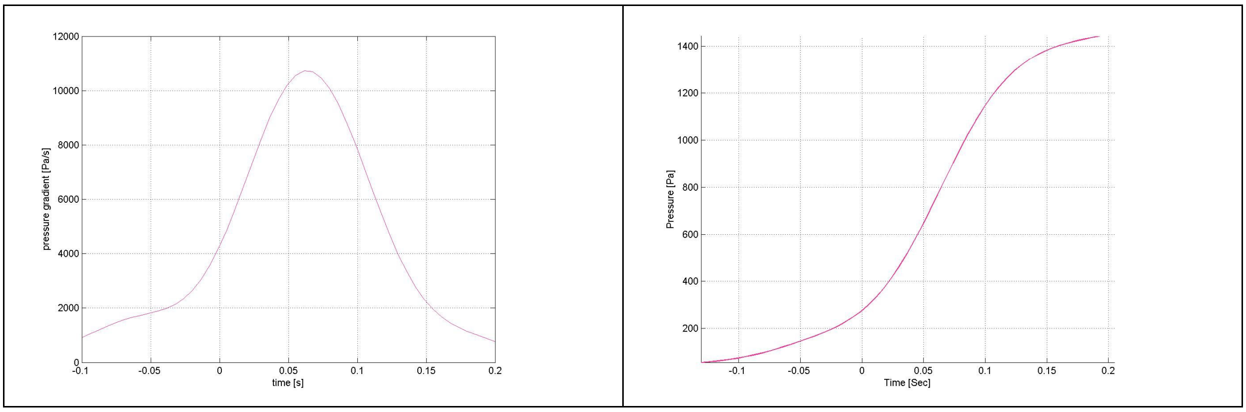


Figure 13 gradient pressure history and pressure history of a TGV Duplex at 270 km/h

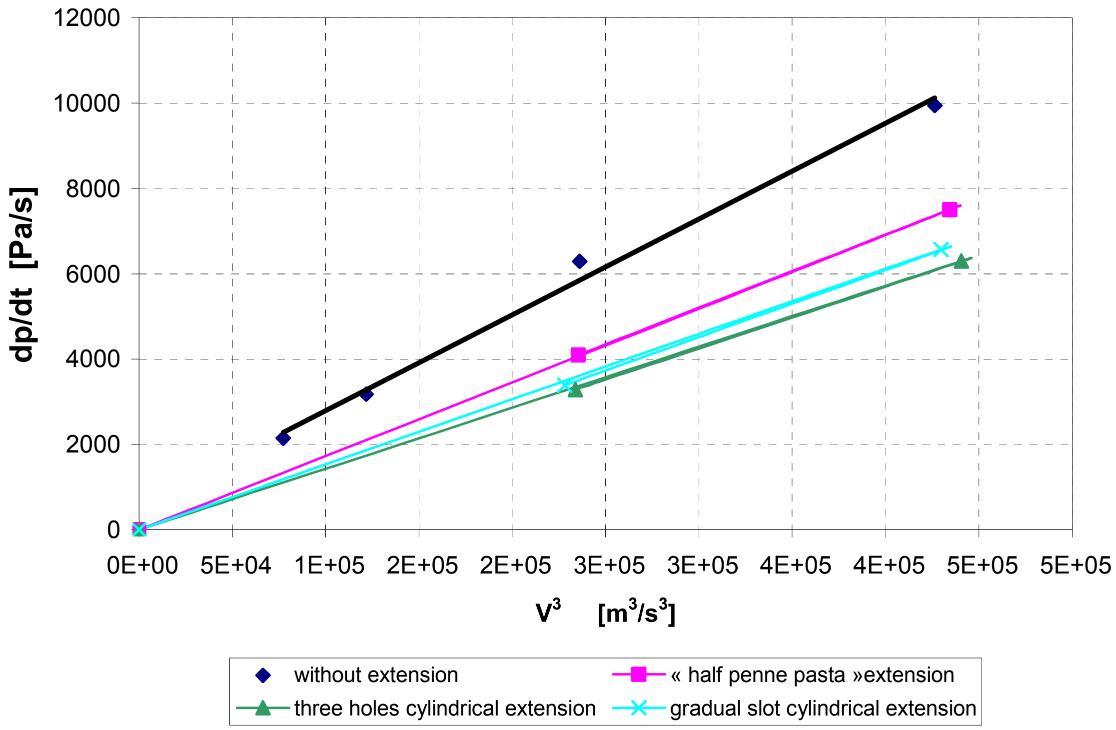


Figure 14 Pressure gradient (done by the entry of the nose) versus speed cubed for TGV Réseau

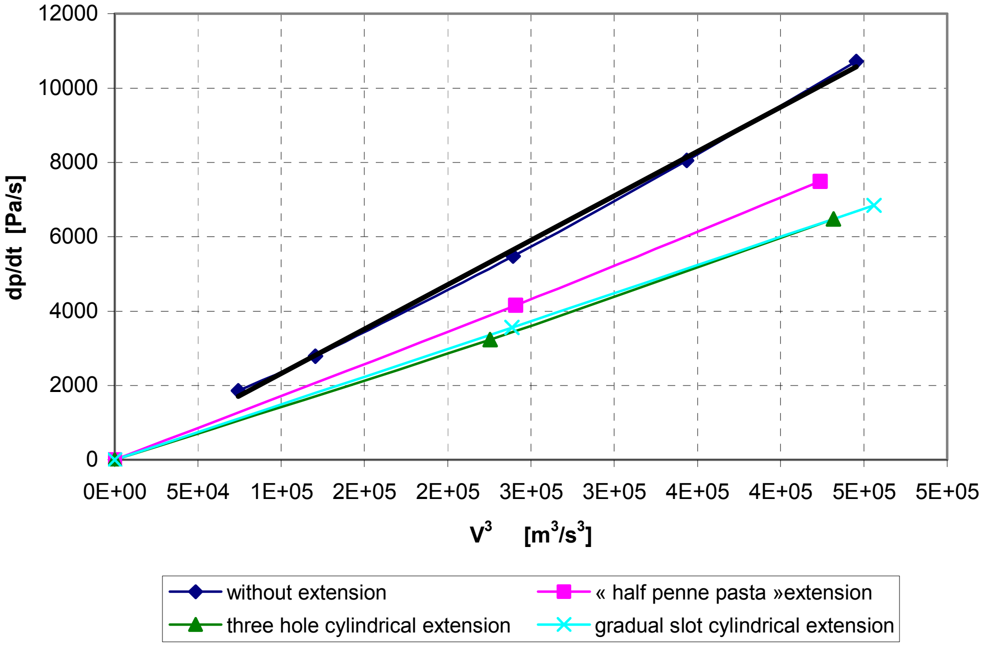


Figure 15 Pressure gradient versus the cube of the speed for TGV Duplex

The results are in general agreement with the theoretical approach in the TRANSAERO Project(4) and scaled measurements. There is a linear relationship between the amplitude of the pressure gradient fluctuation and the cube of the speed.

As in Reference 5, a greater reduction of pressure gradient is obtained with the three-hole cylinder extension and with the gradual slot cylinder extension

It can be noted that the reduction of the maximum pressure gradient at the highest speed which is achieved with both the three-hole cylindrical extension and the gradual slot cylindrical extension is approximately 37% compared with the plain tunnel portal. This is less than the 57% reduction calculated in the TRANSAERO Project.

8 CONCLUSIONS

A series of tests has been conducted on the MMR for SNCF. Over thirty tests were conducted for different train types, train speeds and tunnel extensions.

The results confirm that the initial pressure rise varied linearly with the square of the speed and the gradient of the initial pressure rise varies linearly with the cube of the speed.

There is no effect of the portal extensions on the variations of pressure ΔP0 and thus on the total variation of pressure, ΔP, one of the main parameters for aural pressure comfort. The tests, however, indicate that short portal extensions can reduce the maximum value of the initial pressure rise gradient by a factor of two.

Such a parametric study serves to establish the effectiveness of short portal extensions in reducing the maximum value of initial pressure rise gradient by a factor of two. The results confirm earlier studies in the TRANSAERO project (5) and Japanese studies(6).

There is currently no clear relationship between the maximum value of initial pressure rise and the maximum pressure gradient, dP/dt, the other main parameter for aural pressure comfort.

The next steps will be to correlate the dimension of the openings with the tunnel dimensions and to explore the influence of the train related parameters

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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