# railways: noise and vibration issues

**by Paul Eade**

***Paul Eade, General Manager of Acoustic Design Ltd.,* describes how railways offer him and his team of noise control and vibration engineers varied and interesting technical problems***

## Introduction

Trains and boats and planes – factories, oil rigs and theatres too. The work of a Noise and Vibration Engineer is varied and touches all aspects of modern life. Railways are perhaps unique in the challenges they bring to professionals involved in the fields of noise and vibration. They fall into three main categories:-

- Environmental effects
- Passenger and employee safety and comfort
- Infrastructure design

Legislative and commercial pressures place demands on a modern railway in all these areas. The methods for dealing with these demands have evolved and become more sophisticated over many years. In the last two decades environmental, safety and competition issues have gained importance.

## Environmental

Running trains generate both noise in the air and vibration in the ground. These two temporary pollutants impinge on the railway's neighbours. Subsidiary activities associated with running a railway, such as track maintenance and marshalling, also create noise and vibration.

### Noise

Noise from running trains arises principally from the motive power units and from the action of the steel wheel rolling on the steel rail – so called wheel/rail noise. As train speeds increase, the importance of wheel/rail noise increases and at speeds typical of modern passenger traffic it is wheel/rail noise that dominates environmental noise emission.

The move away from using tread braking for rolling stock with cast-iron brake blocks has resulted in significant reductions in levels of wheel/rail noise radiation. Typically rolling stock which is disc braked is quieter than cast-iron treaded braked stock by 8dBA (a very significant reduction) at speeds of 160 kph. This effect can be observed in train sets which contain a mixture of older, tread braked, and newer, disc braked stock.

The change in braking has resulted in a smoother rolling wheel/rail contact with resultant reduced noise radiation. Other attempts at reducing levels of wheel/rail noise have centred on ensuring the smoothness of rails, by removing corrugations, and reducing the vibration response of the wheel and rail to excitation caused by rolling. Vibration damping has been applied to wheels but these techniques have resulted in small reductions in rolling noise although they are very effective at controlling curve-squeal. Bogie shrouds have been tried but noise reductions obtained have been small. Lineside noise barriers are effective, when appropriately designed, but can have the disadvantage of spoiling the view for passengers.

Until relatively recently in the U.K., railways were not covered by the standard planning and environmental legislative framework. The situation has now changed due to legal

*Figure 1.*
*Examples of resilient wheel design*

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*Figure 2. Maintenance work is often carried out at night*

requirements for environmental assessments for new projects, which cover certain types of railway development. Pressure, in part brought about by proposals for the Channel Tunnel Rail Link (CRTL), has also resulted in the Noise Insulation (Railways and other Guided Transport Systems) Regulation 1996. These allow for compensation or mitigation measures to be applied when dwellings are exposed to increased noise due to new or altered railway lines. The Regulations do not cover changes in the use of existing lines, for example, due to increased traffic. The Committee that was set up to recommend the basis for the 1996 Regulations concluded that environmental noise due to rail traffic was less annoying than road traffic at the same noise level. This differential has been called the "Railway Noise Dividend".

Operating a railway can give rise to many forms of environmental noise emission other than that due to running trains. Maintenance work is often carried out at night. The machinery, and the men, generate noise. Careful control can be required to ensure residential neighbours are disturbed as little as possible. Communication with neighbours can pay an important part in this. Station announcements do cause problems. Appropriate design of public address systems can alleviate such difficulties. Problems have been known to be caused by inappropriate use of locomotive horns – where train crews have used horns for "unauthorised communications" during marshalling activities at night... and the list goes on.

## Vibration

Noise transmits through the air to the environment. The other medium connecting the railway with its surroundings, is of course, the ground. In the case of lines in tunnels or underground railways it is the only medium.

A moving train creates a moving force pattern on the ground. The nature of this force pattern is modified by the elements between the train and ground, the rail, the rail supports, the sleepers or continuous slab, the ballast etc. The force gives rise to propagating waves within the ground and a number of types of wave can exist. For surface railway lines it is usual for a form of waves known as Rayleigh waves to dominate propagation to a distance. Rayleigh waves can have relatively slow speed in the ground and long wavelengths (many metres) dependant on ground conditions. These properties give rise to particular problems. In some circumstances (high train speeds and soft ground) it is possible for trains to travel faster than the speed of Rayleigh waves in the ground. A phenomenon analogous to an aircraft supersonic bang then occurs, with very large increases in ground vibration level occurring for small increases in train speed.

***This phenomenon has been reported from a site in South West Sweden when the 2x high-speed train was introduced. Rayleigh wave speeds in the ground at the site were estimated at about 160kph. Train speeds changed from 140kph to 180kph with a resultant ten-fold increase in ground vibration levels. This gave rise to severe disturbance to buildings in the near vicinity of the railway.***

In situations where very long wavelengths predominate, usually associated with heavy freight trains, control of vibration is very difficult. Mitigation measures which are of benefit for shorter wavelengths, for example creating discontinuities in the ground or using piled foundation for buildings, are less effective.

Vibration from trains manifests itself in two main ways. In some situations it can be felt by people and the effect can be exacerbated by floor resonances within a building. Secondary effects include noise radiation and disturbance of fixture and fittings. It is not unusual for sensitive buildings, for example the International Convention Centre in Birmingham above the lines out of New Street Station, to be supported on resilient bearings to control the vibration input and resultant noise radiation in the building.

Many parameters affect train vibration and propagation. Heavy freight trains do give rise to specific problems, particularly when the wagon suspension system employs friction damping as such dampers can "lock". If this occurs effective unsprung weights are high and vibration generation is efficient.

Frequencies of vibration are low, below 10Hz, and wavelengths in the ground long, tens of metres. Sites exist where vibration can be felt in the ground at over a hundred metres from the railway and the sensation is dramatically enhanced sat in a car whose own suspension amplifies the ground motion!

Passenger trains and underground trains tend to give rise to higher frequency vibration. This is often perceived as a rumble in buildings close to tube lines, for example. Feelable vibration can however still be produced if the building, usually the floors, exhibits a resonant response. A particular feature of trains tending to give rise to higher vibration is that of axle-hung traction motors. Again the relatively high unsprung mass is to blame.

Vibration can be mitigated by vehicle design and also by utilising isolation systems within the trackform design. Such features include resilient baseplates, ballast mats and full floating track slab systems. These systems are not effective at dealing with the type of low frequency vibration that arises from heavy freight trains. Buildings adjacent to railways can also be designed to minimise vibration pick-up and amplification. Techniques include piling, sleeved piling, resilient foundation bearings and floor resonance control.

## Rail vehicles

Rail Vehicle design has evolved to give passengers in modern vehicles a high standard of comfort and this includes relatively low noise levels. The French TGV stock is a successful example of this. Constraints of the vehicle designer have always included price, weight, space and ease of

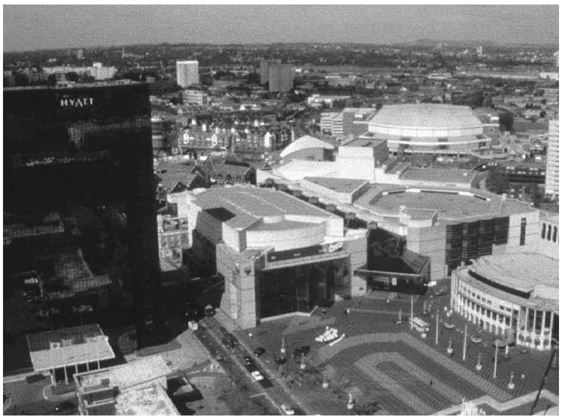


*Figure 3. National Convention Centre and adjacent Symphony Hall – Birmingham*

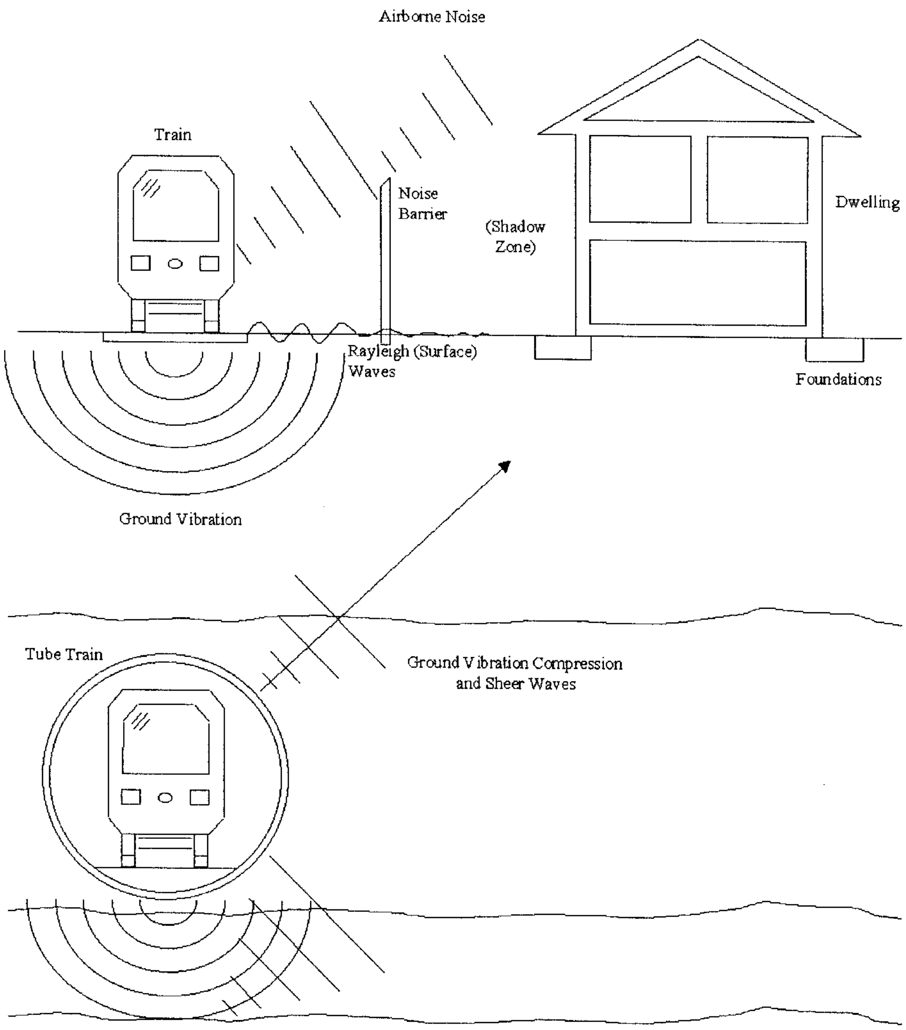


*Figure 4. Railway environmental noise and vibration transfer paths*

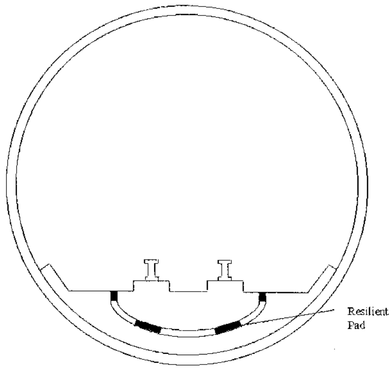


*Figure 5. An example of floating slab track*

*Figure 6.*

assembly but modern commercial pressures, exemplified by the U.K. privatised environment, have placed more focus on these factors.

The noise level inside a running railway vehicle is generated in part by transmission of airborne external wheel/rail noise and motive power and auxiliary equipment noise through the vehicle envelope. An additional so-called "structure-borne" component is caused by direct transmission of vibration into the body shell from bogies and mounted equipment. This vibration then causes noise radiation from the vehicles internal trim panels. Control of internal noise levels therefore broadly revolves around ensuring the vehicle envelope provides adequate sound insulation against airborne noise and that bogie, equipment and trim panel mountings adequately control structure-borne noise. The skill of the noise and vibration engineer is needed to ensure an optimisation of design so that specified internal noise levels are achieved with minimum weight and space. To assist he has at his disposal a number of computer modelling tools.

Particular challenges are presented by the design if air conditioning systems, inter vehicle gangways, sleeper booth bulkheads, the optimisation of the use of vibration damping materials on bodyshells and trim panels and the control of auxiliary equipment noise (e.g. tones from power invertors).

A further area of design in modern rail vehicles is that of the train public communication system. The rail vehicle environment presents particular design problems for such systems which are typically specified using speech intelligibility indices. Specified intelligibility has to be provided against a varying ambient and passenger activity noise level.

Train crew have to be provided with a working environment which is safe. This involves ensuring their daily noise exposures are within current guidelines. In the U.K. these are less than 85dBA Leq,(8hr). Locomotive and multiple unit cabs, guards accommodation etc all has to be

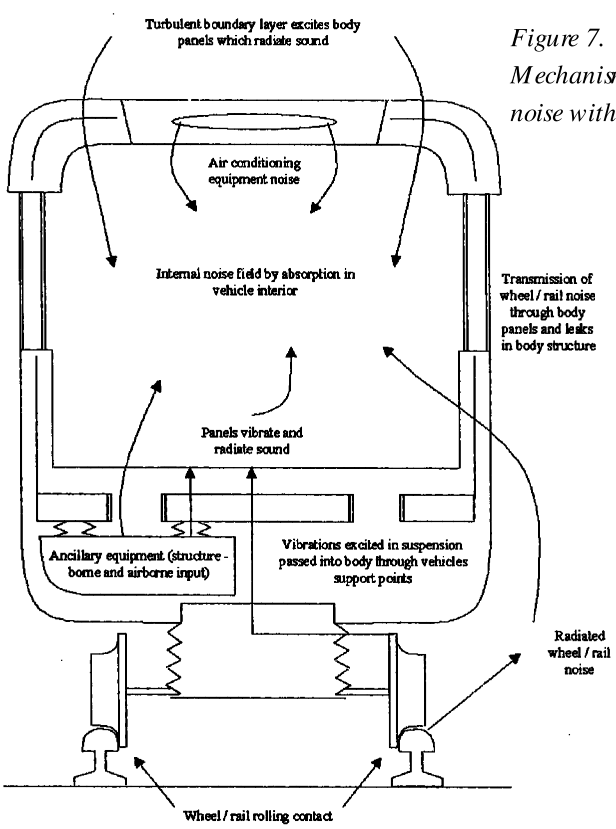


*Figure 7. Mechanisms that generate noise within a rail vehicle*

*Figure 8. Alstrom Arlanda Airport – Stockholm Cabs being Insulated*

designed to ensure ambient noise levels due to wheel/rail and equipment noise is adequately controlled. The techniques used are similar to these outlined for passenger accommodation. In addition train crew are subject to audible signals from systems such as AWS, communication systems and train external warning horns. All these sources need to be included in daily noise exposure calculations.

Trains operating throughout in tunnels present a particularly severe design case.

***The Channel Tunnel Shuttle Locomotive noise specification called for cab noise levels of 78dBA in the tunnel at 160kph and driver noise exposure of 77dBA Leq. To achieve these levels required cab envelopes with resiliently mounted floors and trim. A 10mm steel plate was included in the cab floors and the cab front window comprised 21.4mm laminated glass with a 11.4mm interlayer. The cab air conditioning unit was designed to attenuate pressure pulses arising in the tunnel and prevent the ingress of the high external noise levels in the tunnel.***

## Infrastructure

The design of track, its support and lineside features are all influential in determining the noise and vibration impact a railway will have on its surroundings. Rail infrastructure however consists of other elements which present unusual challenges to the noise and vibration engineer.

Stations, both underground and surface rail, tend to be highly reverberant. To an extent this does add to the ambiance of space but gives difficulty in achieving adequate intelligibility for public address (P.A.) systems. Innovative design of the P.A. utilising increased numbers of speakers and directional speakers in carefully selected locations together with appropriate driver electronics goes some way to alleviating problems. It is however usually necessary to incorporate sound absorbent treatments into station spaces to achieve good P.A. intelligibility. Problems with the durability, cleanability and appearance of such treatments often assume greater importance than their acoustic performance.

Ticket purchase at the station can be fraught if the acoustic transmission of the security screen between the customer and booking clerk is not adequate. Problems are exacerbated by the fact that the customer is often in a reverberant environment.

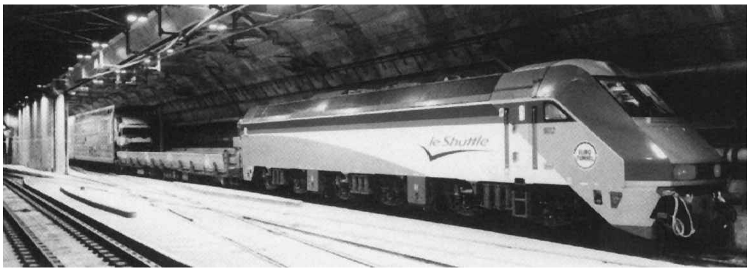


*Figure 9. Le Shuttle*

***Waterloo International Eurostar Terminal is unusual in that the station accommodation is principally below the platforms. In essence the station is therefore a building with trains running on the Òop floorÓor track support slabs. The stations glazed arched roof and west side wall are supported from the same structure as the trains. This presented a number of unusual design problems.***

***The glazing support systems and ceiling and building services equipment supports, beneath the track slabs, are all designed to cope with vibration imposed by the Eurostars running in and out of the station; the design aim being that the trains should create no visible motion of the glazing and no audible rattles in the ceilings and services. Services and other systems were also designed to ensure their performance life was not impaired by the train induced dynamic vibration environment.***

*Figure 10. Waterloo International Eurostar terminal*

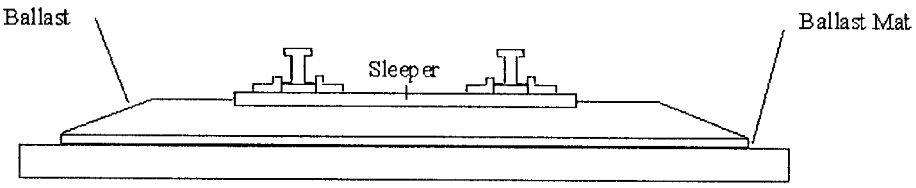


*Figure 11.*
*The Principle of the Ballast Mat*

Trains passing over bridges often produce more noise than trains at grade or on embankment or in cuttings. In severe cases noise level can be up to 20dBA higher. This is due to the fact that, steel bridges in particular, present a large relatively lightly damped structure which is directly connected to the rails. The bridge therefore acts as something like a sounding board in a musical instrument. Concrete bridges do not suffer from this problem to the same extent. With steel bridges mitigation is possible by the use of ballast and resilient track support.

Major areas of involvement for noise and vibration engineers in the railway industry have been outlined. There remain a large number of other smaller facets of the industry where noise and vibration can be a concern.

With the assistance of the skills of the Noise and Vibration Engineer railways progress to a quieter future.

## References:

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## interesting fact

The earliest attempt at building control in Europe, recorded in the Fitz-Alwyn Assize of 1189, required party walls to be built of stone at least three feet thick, primarily for reasons of structural stability but also 'for appeasing contention which sometimes arise between neighbours'. Sound insulation seemed to have been adequate until the mid-nineteenth century, when the modern piano became commonplace and, despite pleas from 'Builder magazine in 1857 to reduce the impact of sound transmission through floors, no measures seem to have been taken until 1948 when the British Standard Code of Practice for Building was published. It took a further 15 years for a set of 'deemed to satisfy' specifications to be published in the Building Standards Regulations.



## keep it short

Reflecting concerns by residents about airport noise, Mayor of New Bedford Frederick M. Kalisz Jr. wants to reduce the length of a proposed New Bedford Airport runway expansion to keep out certain, loud cargo planes. The mayor's proposal, to increase the runway from 5000 to 6800 feet would allow certain cargo and passenger planes to use the airport, but the runway would not be long enough for the older model 727 cargo planes. "We are not going to approve a runway that allows these airplanes with a high noise problem to come to New Bedford," the Mayor's spokesman said. "These planes would substantially degrade the quality of life in this area..." By only building the runway to 6,800 feet, he argued, "We can dictate the type of planes that come here." He went on to say that restricting the length of the proposed runway extension would prevent New Bradford from becoming a dumping ground for older, louder planes that are sent to fly their last flights at smaller regional airports.

noise notes