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SILENT FREIGHT AND SILENT TRACK PROJECTS

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ABSTRACT
Noise from moving freight trains is the major environmental concern for Europe's railways and has been the subject of national and co-operative research for a number of years. Using experience gained and tools developed from this research, particularly the rolling noise simulation software TWINS, consortia of railway administrations, universities, consultants and industry successfully developed a number of low noise prototypes in the EU sponsored 4^{th} Framework Brite Euram projects Silent Freight and Silent Track. These projects, which commenced in 1996 and 1997 respectively, had the combined objective of reducing rolling noise from the operation of railway freight vehicles on ballasted track by at least 10 dB(A) by mitigation measures applied at the source. This paper gives the background and conclusions to those projects.

1 - INTRODUCTION
Noise is the major environmental concern for Europe's railways. Reducing noise from freight operations has particularly high priority because there are significant night-time freight movements, when noise limits imposed by legislation are lower.

Rolling noise, caused by the action of the steel wheel on the steel rail, is the major noise source. The freight vehicle noise problem is exacerbated by the widespread use of cast iron tread brakes which are known to give rise to higher levels of rolling noise than when other forms of braking are used. Unfortunately, braking requirements are such that in Europe only cast iron tread brakes are approved for international freight operation, although this situation is currently under review.

In 1996 and 1997, three EU sponsored 4^{th} Framework Brite Euram projects, Silent Freight, Silent Track and Eurosabot commenced, aimed at reducing the noise from the operation of Europe's freight trains.

Eurosabot investigated the methodologies by which alternative designs of tread braking could be employed that would produce smoother wheels and hence less noise. From experience with disc brakes, it was likely that, this would yield no more than a 10 dB(A) reduction in noise relative to cast iron tread braking technology.

In the long term, even if successful, such a reduction would be unlikely to satisfy future environmental needs or legislation. Further reduction at source would be required as an alternative to increased use of high trackside noise barriers. There is also a school of thought which says that environmental noise levels will only be reduced by the imposition of strict noise creation guidelines.

The Silent Freight and Silent Track projects were initiated to provide additional reduction and the combined objective was to reduce rolling noise from freight vehicles on ballasted track by at least 10 dB(A).

2 - CONSORTIA
The projects were carried out by the following consortia:

Silent Freight: ABB Corporate Research *Sweden*, Construcciones y Auxilair de Ferrocarriles (CAF) *Spain*, Valdunes *France*, TNO Institute of Applied Physics *Netherlands*, Vibratec *France*, Integral *Austria*, Chalmers University *Sweden*, Centro de Estudios e Investigaciones Técnicas de Guipozco (CEIT) *Spain*, Institute of Sound and Vibration Research (ISVR) *UK* and ERRI *Netherlands*.
ERRI received technical support from: BRR (AEA Technology Rail) *UK*, Deutsche Bahn AG *Germany*, London Underground Limited *UK*, SNCF *France* and NSTO *Netherlands*.
Silent Track: British Steel *UK,* Pandrol *UK*, SNCF *France*, SOGERAIL *France*, Chalmers University *Sweden*, Vibratec *France*, Technical University Berlin *Germany*, ISVR *UK* and ERRI *Netherlands* .
ERRI received technical support from: Banverket *Sweden*, BRR (AEA Technology Rail) *UK*, Deutsche Bahn AG *Germany*, London Underground Limited *UK*, SNCF *France* and NSTO *Netherlands*.

3 - METHODOLOGY

Rolling noise is a forced vibration process where forces generated within the wheel/rail contact zone cause wheel, rail and sleepers to vibrate and hence radiate noise. Past cooperative research among Europe's railways has led to the development and validation of a model named TWINS (Track-Wheel Interaction Noise Software) to simulate this rolling noise process [1], [2]. This program takes account of the effects of wheel/rail interaction, wheel, rail and sleeper dynamic response, wheel, rail and sleeper noise radiation and noise propagation. The flow diagram is given in Figure 1.

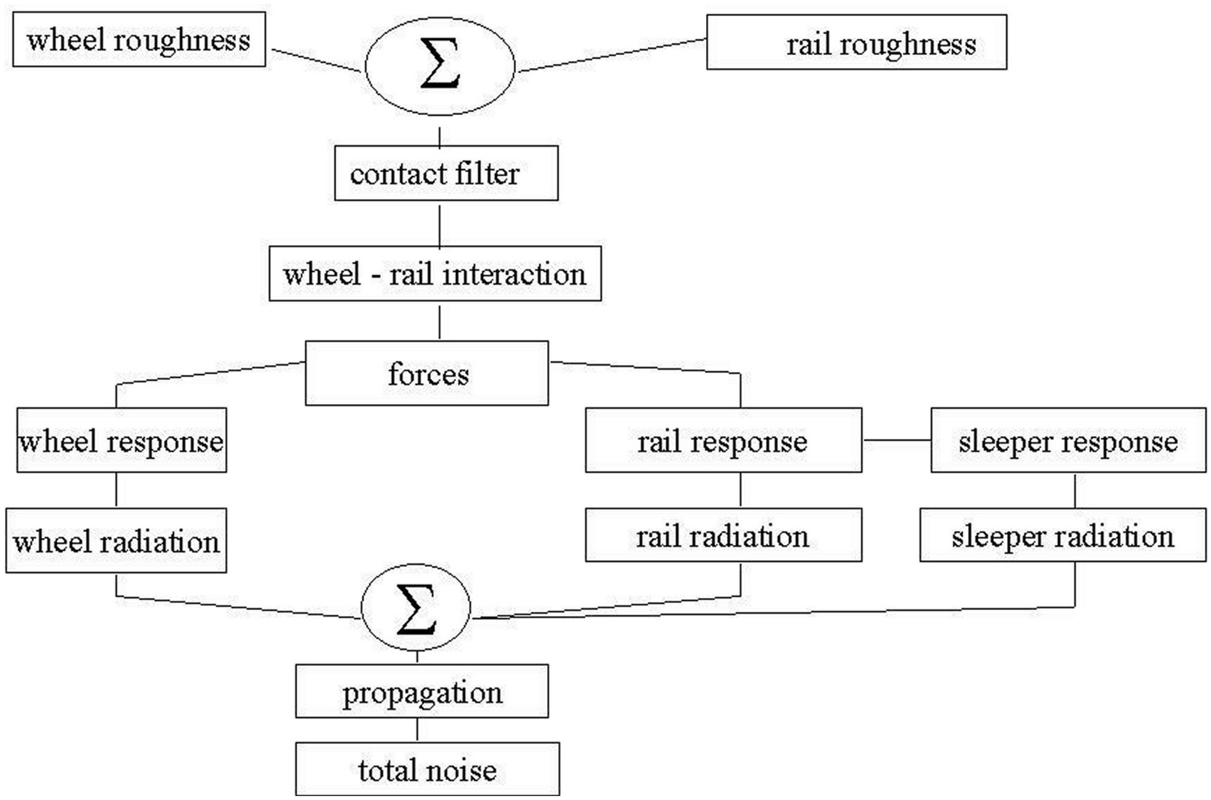

Figure 1: Flow diagram for TWINS software.

The force in the contact zone, and hence the noise is dependent on the surface roughness of wheel and rail.
It is also known that the level of roughness on the wheel is dependent on the form of braking. For instance, vehicles with cast iron tread braking, where the brake block makes direct contact with the rolling surface during braking, gives rise to rolling noise levels about 10 dB(A) higher than vehicles with disc brakes, at the same speed, because the braking action causes inherently higher wheel roughness.
The flow diagram shows that the potential areas where noise control is possible (excluding the wheel roughness areas investigated by Eurosabot) are:

- Wheel/rail interaction
- Reduction of wheel/rail/sleeper response

- Reduction of wheel/rail/sleeper radiation
- Increase propagation losses

The contribution each component makes to total rolling noise is dependent on its detailed design but it is common to see approximately equal contributions from vehicle and track.
The reference designs for these projects were vehicles with 920 mm dia. wheels on ballasted track, with concrete sleepers supporting UIC 60 rail on soft rail pads. In this situation track noise dominated wheel noise by about 8 dB(A) and even significant reductions in noise radiation from the wheel would have little effect on total rolling noise. It was therefore important to assess each project's success in reducing vehicle and track contributions separately.
The contribution of freight wagon superstructure to overall noise was also to be assessed.
The general approach in the development and validation of noise mitigation designs was to:

- Review alternative options and define dynamic properties using TWINS software
- Assess effectiveness of design by laboratory/rig tests
- Validate design principles by full scale testing of prototypes

This approach had been shown to be successful in an earlier ERRI study on freight vehicles and track [3].
It was also envisaged that the TWINS software would be updated based on experience gained during the projects and that additional modules would be required to enhance its capability particularly in the area of added damping, local shielding of wheel and rail and, if necessary, superstructures.

4 - NOISE MITIGATION

4.1 - Wheel rail interaction

At the start of the projects, there were suggestions that conforming contacting profiles would give rise to lower noise levels. However, it was demonstrated in these projects and elsewhere that this was not the case [4].

4.2 - Wheel size and shape

Wheel design can be optimised by using smaller wheels, to reduce the number of resonances within the frequency range of roughness excitation, and with a more symmetrical cross section, to minimise the axial motion of the wheel web due to radial forces at the tyre [3]. Additionally, increases in web thickness will increase wheel natural frequencies and reduce web vibration.
Unfortunately, such an approach has to be limited for practical reasons, particularly the thermo-mechanical implications of the energy input to the wheel during braking (Silent Freight wheels were designed, in most cases, to be tread-braked).
A wheel diameter of 860 mm was chosen and optimum cross sections, consistent with residual stress requirements for cast iron tread braking, incorporated into designs.
These measures were predicted to reduce the wheel contribution by 5 dB(A).
An additional option was to incorporate perforations into the wheel design to provide low frequency noise reduction through acoustic short circuiting. The prototype design was predicted to give a reduction in wheel sound power of $6 - 9$ dB at frequencies below 1000 Hz.

4.3 - Added damping

Two options were chosen for prototype development.

- Ring dampers were used with perforated wheels to provide high frequency reduction complementary to the low frequency noise cancellation derived from perforations
- Tuned absorbers were designed for solid optimised wheels and rails

The wheel absorber, tuned to the two nodal circle radial mode, was predicted to provide a 5 dB(A) reduction in wheel sound power.
The rail absorber was designed as a "stacked" system and tuned to two frequencies, 630 Hz and 1350 Hz. This combination was predicted to reduce the rail sound power by about 7.5 dB(A).
The options of constrained layer damping, resilient wheels and the use of composite materials were considered in the early stages of the projects but were eventually rejected for various reasons.

4.4 - Wheel mounted screens

Since the major contributor to wheel radiated sound is the vibrating web, one possible way to reduce wheel sound power is to shield the web with a wheel mounted device.

The concept was taken to prototype design in combination with a smaller diameter solid wheel and optimised cross section.

The reduction in wheel sound power was predicted to be about 8 dB(A)

4.5 - Rail pad stiffness

It is predicted [5] that track radiation is at a minimum when rail vertical and sleeper components are equal. This generally requires a stiff rail pad, which can have an adverse effect on rail roughness growth and sleeper impact forces. Notwithstanding these considerations, a stiffer rail pad (800 MN/m compared with 300 MN/m reference) was taken forward for prototype testing.

4.6 - New track design

Modelling indicates that significant noise energy is radiated by the rail foot in bending. One mitigation option considered was a rail cross section with a narrower rail foot. An alternative rail support, under the rail head, was also included in this design to maintain rail head lateral stability.

In conjunction with an optimised twin block sleeper, this was designated the ”new track” design.

4.7 - Propagation control

Following earlier studies, the use of bogie shrouds in combination with low trackside barriers was also considered. For maximum benefit it is necessary for the bottom of the shroud and top of the barrier to overlap. Unfortunately, a design that would be compatible with all European loading gauges left a gap of 168 mm between the bottom of the shroud and the top of the rail. This limited the effect of the shroud/barrier combination to a predicted 5 dB(A).

5 - RESULTS

Validation of the performance of the low noise designs and comparison with the predicted benefits was carried out on the Czech Republic test track at Velim.

Test sections based on the retrofit and new track options were constructed, and optimised wheels mounted on two-axled flat wagons. A separate test train of bogied vehicles was used to measure the effect of bogie shrouds and low trackside noise barriers.

The results, expressed as a reduction of total noise in dB(A), are presented below. (The first row and column give the reduction of track and wheel contributions to noise respectively).

	Wheel noise reduction ↓	Stiff pad	Ref track + TA	Stiff pad + TA	New track	New track + TA
Track noise → reduction		2	6	5	3	7
Perforated wheel + ring damper	4.5	2.1	5.6	4.3	2.2	5.8
Optimised wheel + shield	8.5	2.7	6.7	5.4	3.9	8
Optimised wheel + TA	7	2.6	6.9	5.6	4.2	7.7

Table 1: Measured rolling noise reduction [dB(A)], TA = tuned absorber.

The results indicate that damping/shielding of wheels and damping of track are necessary to achieve any reasonable reduction in rolling noise. For damped wheels on retrofit track, the upper limit of noise reduction is approximately 7 dB(A) and for damped wheels on the new track design the upper limit is about 8 dB(A).

Measurements for the bogie shroud (168 mm gap to top of rail) in combination with low trackside barriers (50 mm above top of rail) indicated a noise reduction of 3 dB(A). The shroud used on its own gave a reduction of between 1 and 2 dB(A), whilst the low barrier, when used alone, gave, as expected, virtually no benefit.

The overall conclusion regarding the designs developed in Silent Freight and Silent Track is that in order to achieve the 10 dB(A) noise reduction objective, it is necessary to have damped or screened wheels, damped track *and* bogie shrouds with low trackside barriers.

6 - ADDITIONAL MODELS DEVELOPED

The following modules were developed to enhance the capability of the TWINS software:

- Wheel Damping
- Modelling guidelines for Resilient and Composite Wheels
- Sound Power Radiation
- Shielding module
- Sound Pressure Level to account for ground absorption
- Guidelines for modelling perforated wheels
- Superstructure module to compute transfer functions for superstructure
- VIBRAIL, to compute receptances for rail on discrete supports and allow for cross sectional deformation.

One work area within the Silent Track project focussed on rail roughness generation and growth. The objective was to obtain a model for rail roughness generation in the acoustic frequencies to assess the influence of track parameters. This would ensure that proposed designs would not have an adverse effect on roughness generation and would ultimately lead to low roughness design principles.

Existing models, developed by partners in the Silent Track project, were modified and extended based on measurements at a number of test sites.

The models, whilst not being able to simulate the results of all measurements, confirmed the importance of soft rail pads and the role of the pinned-pinned resonance mode of the rail on the sleeper in the rail roughness generation process.

Parametric studies using these models have led to the definition of a number of low rail-roughness growth design principles.

7 - CONCLUSIONS

- Comparison of predicted benefit with that obtained by measurement of full scale prototypes in field tests showed good agreement confirming the methodology used in these investigations to be valid
- In order to achieve the 10 dB(A) noise reduction objective, it is necessary to have damped or screened wheels, damped track *and* bogie shrouds with low height trackside barriers.
- The testing demonstrated that the hard rail pads produce no additional benefit when used with damped track. This may remove some of the areas of conflict between acoustic and railway engineering requirements.
- The benefit of optimised wheel cross sections was less than originally predicted. It may therefore be easier to match the acoustic and residual stress requirements, particularly for wheels with composite brake blocks.
- Superstructure noise, even from what are considered to be noisy wagons when empty, is at least 20 dB(A) below rolling noise. It will remain below rolling noise even with the use of the low noise components developed in the project.

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