Road Traffic Noise Emission: Recent Developments and Future Prospects

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ABSTRACT

Road traffic noise is one of the major environmental concerns of densely populated areas all over the world. Road vehicles are by virtue of their number, their travelling speeds and their power output a potent sound source. In the past noise reduction efforts have very successfully focused on the engine, the power train and exhaust system. Nowadays the major part of noise emitted by vehicles on roads in the mid- to high-speed range is due to tyre/road noise, which may vary more than 15 dB depending on the tyre/road combination at a given speed. Both tyres and road surface must be considered in order to achieve noise reductions. This article aims at presenting the possibilities for noise abatement offered by technologically advanced pavements, tyres and vehicles.

With the introduction of noise-reducing pavements like porous asphalt low-noise options have become available to road authorities. However, properties other than noise emission like skid resistance or long-term durability often supersede it in the decision making process. The well established guidelines for road construction usually do not take modern low-noise pavement variants into account.

Tyres are subject to a long list of requirements, and low noise emission usually ranks rather low on the private buyer's priority list. Currently initiatives are under way to improve the measurement methods for tyre noise emission, the reference surface used for testing and the noise limit values.

From a technical and scientific viewpoint, the advantages of reducing noise at the source are obvious. Noise that is not generated does not propagate, need not be deflected or absorbed and reduces the noise immission levels in large areas.

Keywords: traffic noise, acoustics, pavement

1. OVERVIEW

Road traffic noise affects densely populated areas all over the world and decreases the health and the quality of life of residents. The high traffic volume makes the today's extensive road networks a very prominent sound source. Regulations and research in the past mainly focused on engine, power train and exhaust system and were successful in reducing the average engine's noise power output. The main contribution to overall vehicle noise emissions has shifted to tyre/road noise (see reference SANDBERG). In the mid- to high-speed range (approximately v > 40 km/h) is due to tyre/road noise (see Figure 1). Engine noise depends on the engine power and the gear setting, whereas tyre/road noise steadily rises with the rolling speed. Tyre/road noise may vary more than 15 dB depending on the tyre/road combination at a given speed, ranging from block pavements to low-noise porous asphalt. In the tyre contact patch the tyre tread pattern interacts with the texture of the top road surface layer which generates complex vibrations of the tyre as well as aerodynamic effects and resonances within the cavities, which are called air pumping. The tyre/road surface combination must be optimized in order to achieve noise reductions.

Tyres are subject to a long list of requirements, and low noise emission usually ranks rather low on the private buyer's priority list. Currently initiatives are under way to improve the measurement methods for tyre noise emission, the reference surface used for testing and the noise limit values.

The choice of using low-noise pavements like porous asphalt has become available to road authorities. However, properties other than noise emission like skid resistance or long-term durability often supersede it in the decision making process. Standard procedures for road construction still do not use modern low-noise pavements to achieve noise abatement in combination with or instead of noise barriers. Nevertheless a lot of research into tyre/road noise is carried out. SILVIA, HARMONOISE, SILENCE and QCITY are current European projects trying to provide information and tools for effective noise reduction.

This paper focuses on the noise emission from single road vehicles and their components interacting with the road surface. Nevertheless it has to be clearly stated that increasing road traffic volumes and especially increasing heavy vehicle road traffic can at least partially offset the noise reduction achieved at the individual sources. As the total noise emission levels increase with traffic volume, heavy vehicle percentage and traveling speed, noise emission reduction can also be achieved to some extent by speed limits and limited access zones. Yet these measures are not only technical in nature, and they tend to conflict with mobility needs. Therefore they have to be intelligently combined with source-oriented noise abatement and noise barrier constructions.

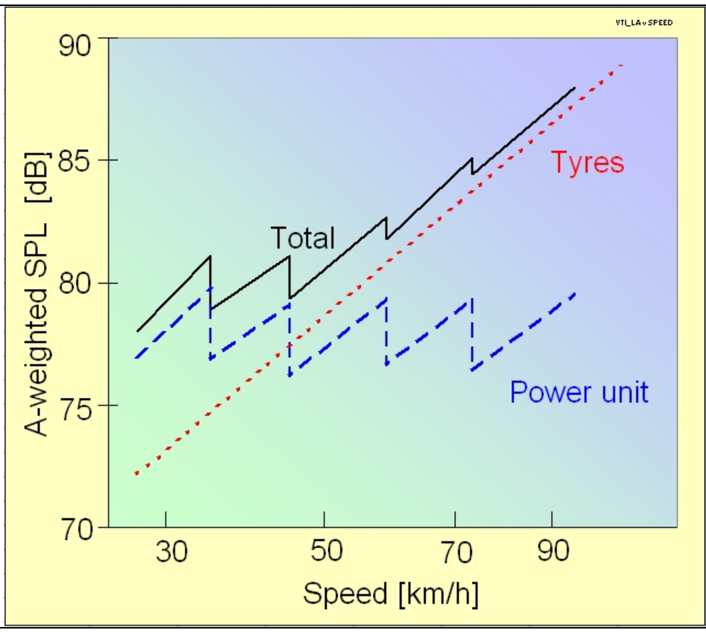

Figure 1 Power unit noise, tyre/road noise and overall noise vs. speed

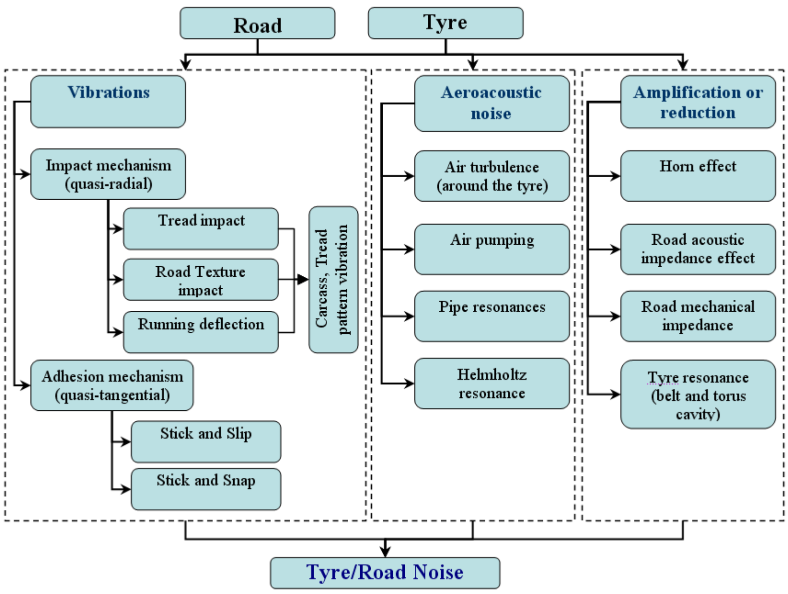

Figure 2 Generation and amplification effects related to tyre/road noise

2. VEHICLES

Road vehicles are designed to comply with regional and national regulations regarding type approval which include maximum noise levels during a certain operation. In the European Union, the relevant regulation is Directive 70/157/EEC. Outside the EU, both within and outside Europe, many countries honour the ECE regulation R51 which is issued by WP29 of the United Nations Economic Commission for Europe (ECE).

Vehicle noise emission limits are intimately connected to the measurement method and mode of vehicle operation during the noise test. There are two different modes of operation: one for light and the other for heavy vehicles. However, common to both is that the measurement is conducted with the test vehicle approaching the test area at a constant speed. The test area shall have a surface meeting the requirements of ISO 10844. When a position 10 m ahead of the microphones is reached by the front of the vehicle, the throttle is opened totally and the vehicle drives by the microphones at full acceleration, closing the throttle when the end of the vehicle has passed 10 m behind the microphones. The maximum A-weighted sound level is measured with two microphones 7.5 m to the left and right of the vehicle path. The measurement method prescribed in the regulations is almost identical to that of ISO 362 (see reference ISO 362).

For light vehicles, the test is performed with the vehicle approaching the test area at a given speed, then accelerating on the 2nd gear. The test is repeated when using the 3rd gear and the final result is the average noise level of the tests, which is compared to the limit value. Powerful vehicles may be required to use the 3rd and 4th gears instead in order to avoid excessive tyre slip. Heavy vehicles need to be tested at a great number of gear settings to determine the maximum noise levels and the approach speed is generally lower. The heavy vehicles are tested unloaded, which means that considerable tyre slip might occur.

Before 1996 (EU and ECE), the limit values put the emphasis of noise reduction on the power unit, whereas the present limits create a need to select tyres for the test that have low noise emission during conditions of medium or high torque. For cars, this has led to attempts to find tyres which emit noise during the test which is 3-5 dB lower than the legal limit for the whole vehicle. For trucks, the tyre noise is not as critical as for cars, but one must avoid tyres which produce large slip and excessive noise at this slip.

The present system has been criticised for using driving operations which are not typical of common traffic flow. Therefore, a new method is being developed internationally. It will include testing heavy vehicles with a reasonable load and testing light vehicles both at constant speed and full throttle operation. The results will be normalized to correspond to a moderate acceleration commonly appearing in real traffic. For light vehicles, it will become very important to reduce tyre noise, whereas their power units will face less stringent requirements than today. There are also attempts to work out a supplementary method to take into account engine noise dominated low-speed situations typical at stop-lights and intersections.

Some experts are dissatisfied with the mixing of requirements on tyres and power units and would prefer to keep them separate. Some politicians would probably not be satisfied with the fact that the stepwise reduction of noise limits in the period 1970-1996 has stopped and no progress has been made for the last decade and will not occur in the next few years. This new type approval system is not likely to be in force for vehicles before 2010.

3. TYRES

In explaining tyre influence on tyre/road noise the most important tyre design characteristics are tread area features, casing construction features and the rubber compound. These are the results of a number of balanced objectives (price, rolling resistance, wet traction, hydroplaning, snow traction, comfort, noise, weight, etc.). The contribution of the different noise generation mechanisms to the total tyre/road noise can be analysed by simulations using tyre models. Figure 2 summarizes the main generation and amplification effects related to tyre/road noise.

The tread pattern influences all noise generating mechanisms (see Table 1, in which ☺ refers to lower noise levels); in practice aggressive treads lead to marginal noise level increases of 1-2 dB. Anyhow, owing to the fact that sound radiation is generated even by smooth tyres, only a limited reduction in the tyre/road noise can be achieved by changing the tread pattern. The influence of the blocks and ribs depends on their geometry and on the road texture. On the one hand, the presence of the tread blocks may cause higher noise levels in the low-frequency range on very smooth roads. On the other hand, smooth tyres emit more noise than standard tyres on rough-textured pavements. The worst examples are tyres with a constant pitch, which generate a very unpleasant noise of tonal character. Therefore treads are usually randomized.

Table 1 Noise emission effects of different tyre/road combinations

Tyre	Smooth road	Rough road
slick tread (smooth)	☺	☹
patterned tread	☹	☺

Tyre design and condition affect the noise emission in several ways:

- Tyre wear and ageing influences tyre/road noise.

- In general harder rubber compounds cause higher noise levels than softer ones, especially for aggressive tread patterns. The elastic modulus of the tread has often a much larger influence than that of the sidewall.

- Studded winter tyres show very significant increases in noise levels compared to the same tyres without studs.

- In general noise emission increases with tyre width.

- The tyre's inner structure influences tyre/road noise**.** Radial tyres are somewhat less noisy than bias tyres. A decrease of the belt stiffness can increase tyre/road noise. Increases of carcass stiffness of truck tyres can result in reductions of tyre/road noise.

- The tyre's sidewall affects the whole tyre vibration due to road megatexture (see 4.1). The sidewall design can also change the level of the sound that radiates away from the tire.

- Small improvements seem obtainable by fitting absorbing material on the rim inside the tyre and by filling the tyre with solid materials.

- Non-uniformities (tyre runout, unbalance) can cause a noise level increase for the interior noise and at low frequencies.

- Tyre load and inflation pressure can also influence the tyre/road noise.

There is a general trend to lower aspect ratios. Some new developments are porous treads and run-flat tyres. Porous treads could absorb sound within their structure. Run-flat tyres are designed to retain their stability even when a perforation and loss of inflation pressure occurs. This is achieved by increased stiffness of the sidewalls, which may lead to increased noise emission.

The type approval testing of tyres with regard to noise emission in the EU is carried out according to Directive 2001/43/EEC (see reference Directive 2001/43/EC) and uses two microphones at 7.5 m distance of a coasting vehicle with the tyres under test rolling on an ISO 10844 surface. The pertinent limit values are currently under review.

4. ROAD SURFACES

4.1 Basic Principles

There are three basic rules for designing a silent road surface, namely:

1. The surface must be provided with sufficiently deep macrotexture (minimum texture depth: 0.5 mm) making up a random, closely packed, homogeneous array of small to medium size aggregates (maximum size: 10 mm) in order to prevent air pumping.
2. Or, the role of macrotexture can be played by a porosity made of pores connected to the surface and to one another (minimum voids content: 20%) which moreover will provide some favourable sound absorption if the layer is sufficiently thick (minimum thickness : 40 mm)
3. Megatexture and large-wavelength macrotexture must be minimised by ensuring in all cases that macrotexture is fine and homogeneous. This holds for porous surfaces too.

In addition, as either macrotexture or porosity provide water drainage at the interface between tyre and road surface, they are beneficial to skid resistance as well.

For additional information on this chapter see also the references SANDBERG, SILVIA, FEHRL and ISO 11819-1.

4.2 Existing Applications

4.2.1 Porous Asphalt

Porous asphalt in new condition (see also Figure 3) reduces tyre/road noise by 3 dB(A), on average, as compared to dense bituminous macadam. However, one should notice that comparisons between individual sections exhibit a wide scatter, so that the largest reduction can go up to 9 dB(A), but an increase up to 3 dB(A) can also be observed. These variations, having been observed on roads free of deterioration, are due to the particular characteristics of the tested sections: megatexture, void content and thickness. When compared to the noisiest surfaces like paving blocks, the best performing porous asphalt provides up to 16 dB(A) reduction of car tyre noise. Regarding the overall traffic noise, the reductions can be less than that for tyre noise alone depending on the traffic speed and the percentage of heavy vehicles.

Regarding the development over time of the acoustical performance of porous asphalt, it can be stated from the experience gained in Europe, that

- except under adverse particular conditions, such as small thickness, void content or aggregate sizes, or very aggressive traffic (studded tyres), a satisfactory stability, i.e., an increase of 2 dB(A) may be expected for noise levels after 3 to 4 years of service, and
- gradual clogging, which creates a serious deterioration of permeability, does not seem to have such a detrimental effect on acoustical performance as could be feared.

Winter maintenance on porous asphalt can be a concern. De-icing agents should ideally be adapted in quantity, quality and intervention strategy, which is easier to write than to implement.

Figure 3 Additional benefits of porous surfaces: less glare and spray in wet conditions

4.2.2 Thin layers

In recent years the use of thin layers or thin surfacings has grown very rapidly in popularity for pavement maintenance operations. These surfaces are thin (15-40 mm), gap-graded bituminous layers coated at the plant and hot rolled. Typically, the grading is 0/6, 0/8 or 0/11 with a gap at the medium aggregate sizes and the binder is bitumen modified with elastomers. They exhibit a surface texture visually similar to porous asphalt and mostly appear on the market under proprietary names. Thin layers have largely replaced the classical surface dressings as a maintenance technique.

Regarding noise, very simplified, one can conclude that thin layers range from being as quiet as porous asphalt to about the same as the best ordinary dense asphalt concrete surfaces. The rather low tyre/road noise emission on thin layers, as compared to classical surface dressings, is due to the smoothing action of roller compaction which, thanks to relatively favourable possibilities for stones to orient themselves with flat and smooth sides towards the top without filling the voids between the stones. This has the effect of aligning them with relatively flat, horizontal sides upwards, hence very little megatexture is created. This is in some contrast to the stones embedded in dense mixes, the orientation of which is more restricted (see Figure 4).

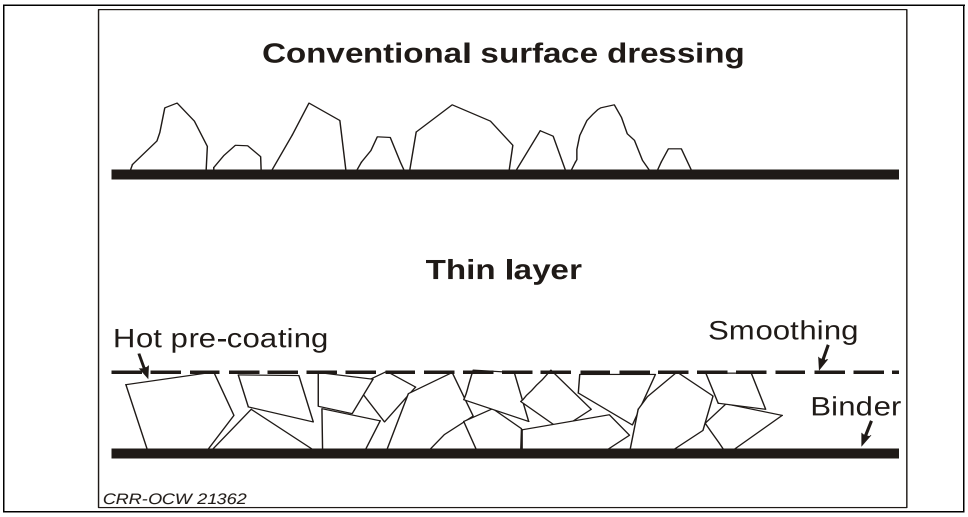

Figure 4 Illustration of the difference of concept between classical surface dressing and modern thin layers

Thin layers are less resistant against tangential stresses; therefore, they are not recommended for use in e.g. crossroads or roundabouts.

4.2.3. Cement concrete: exposed aggregates

The exposed aggregate technique consists of spraying a set retarding agent (essentially sugar) on the fresh concrete surface and brushing away the mortar that has not set after one or two days, creating a certain surface texture by exposing the aggregates.

Very good performance regarding tyre/road noise reduction can be achieved only if some good practice rules are complied with:

• the grading must be optimised (for instance: by increasing the 4/7 or 7/10 fractions w and avoiding larger fractions, which means using much smaller aggregate than compared to a normal grading primarily optimised for strength.) so as to obtain a rather fine, homogeneous macrotexture and,

- a longitudinal smoothing beam must be used instead of a transverse one in order to avoid creation of unnecessary megatexture.

Provided those conditions are carefully respected, optimised cement concrete can give tyre/road noise emission even better than dense asphalt pavements while easily meeting other comfort and safety requirements such as those related to evenness and skid resistance. High durability and high skid resistance requires high-quality aggregate to be used in the full depth of the wearing course layer.

4.2.4. Epoxy-bound surface dressing

This is a high-performance surface dressing which consists of a layer of resinous binder densely spread with small size, highly polish resistant aggregates. This technique is mainly used at critical points on roads like sharp curves and at intersections where a very high and durable skid resistance is needed. Though originally not designed for low noise emission, it appeared to be the quietest non-porous surface type in a number of studies in Europe. The reasons are that the initially liquid binder smoothens out any megatexture of the underlying surface and that the closely packed array of thin stones forms a uniform, fine, but also deep macrotexture. The main problem is the rather high cost because all components must be of high quality.

4.3 Ongoing Developments

The quietest road surfaces today are either porous and sound-absorbing or texture-optimised and dense. All these solutions offer a similar traffic noise reduction potential, i.e., roughly 3 dB(A) compared to an ordinary dense bituminous concrete. The latter give tyre/road noise emissions 5-10 dB(A) lower than the noisiest rough-textured surfaces like paving blocks or old-fashioned cement concrete. Currently two ways for further improvement are being tested. One aims at optimizing the sound absorption characteristics of the pavement. The other explores the noise reduction potential and the feasibility of using very soft, elastic wearing courses essentially made of recycled rubber.

Sound absorption is not the sole factor that explains the noise reducing property of porous surfaces. The prevention of air pumping by the “air drainage” of the open texture plays the major role in the case of thin layers, which do not provide a substantial sound absorption. A stronger effect of sound absorption can be obtained when the peak absorption frequency matches the peak of the vehicle noise spectrum. This can best be achieved with two superposed porous asphalt layers with different gradings. It is possible to tune the frequency of maximum absorption to the desired frequency thanks to more degrees of freedom provided to the designer of a double layer pavement.

The possible influence of the pavement stiffness on tyre/road noise is still debated. When taking macro- and megatexture into account, the apparent systematic difference of noisiness between cement-bound and bituminous-bound pavements can be explained by the former having generally higher levels of megatexture than the latter at equal macrotexture level. There are no indications that the addition of recycled rubber, or elastomers in general, to the binder in normal quantities significantly helps to reduce noise levels. However, when rubber is the main ingredient, as in the case of the so-called "poro-elastic" road surfaces investigated in Japan and Sweden, dramatic vehicle noise reductions can be obtained. In the latter case many problems still remain to be solved, namely concerning wet friction, durable adhesion to the base, strength of base course before the solution can be implemented on a full-scale basis.

5. OUTLOOK

From a technical and scientific viewpoint, the advantages of reducing noise at the source are obvious. Noise that is not generated does not propagate, need not be deflected or absorbed and reduces the noise immission levels in large areas.

The reduction of road traffic noise is both a challenging engineering task with a potential for providing a substantial contribution to the improvement of the quality of life of many people who are exposed to high noise levels. In the future new technological developments, improved approval testing methods and growing expertise in vehicle, tyre and pavement technology will work together to decrease the generation of noise at the source where it is most efficient.

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