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Tyre/road noise – Myths and realities

Ulf Sandberg
Swedish National Road and Transport Research Institute, SE-581 95 Linköping, Sweden
E-mail: ulf.sandberg@vti.se

Abstract

At this conference, the subject of tyre/road noise is on the agenda to a greater extent than ever before. This paper aims at giving an insight into the past, present and future of tyre/road noise emission in the society as well as its control. This is made by means of exploring some myths and realities related to the subject. The following myths are explored:

1. *Tyre/road noise has become a concern only during the last decades, say from the 1970's.* It is shown that already long ago tyre/road noise was an important issue.
2. *Tyre/road noise is an important part of vehicle noise at speeds above 50 km/h (70 for trucks).* The truth is that nowadays tyre/road noise dominates during almost all types of driving for cars and down to about 40 km/h for trucks (vehicles meeting EU requirements).
3. *Manufacturers have done a lot to reduce vehicle and tyre/road noise.* Yes, in some respects; but yet it seems that vehicle noise sometimes has increased rather than decreased.
4. *The speed influence is large but not very interesting.* It is shown that there are unexpected relations between speed-related factors and that these can be useful in data presentation.
5. *Different road surfaces may give a large variation in noise levels.* True, the variation is very large, albeit the most common and useful surfaces are close together on the noise scale.
6. *Tyres do not differ very much in noise emission.* This is not true, the variation is large if sufficiently many tyre types are included in the data set.
7. *Winter tyres are much more noisy than summer tyres.* This is a myth based on the past. Currently, winter tyres may be the "quiet" tyres.
8. *The width of the tyre is a very influential factor.* Essentially true: A noise-width relation covering the range from "tiny" bicycle tyres to large truck tyres is presented.
9. *Tyre/road noise from a heavy truck is far above that of a typical car.* Not true, one may find heavy trucks that emit lower tyre/road noise than some cars.
10. *Tyre/road noise is very broadband nowadays.* True and not true - current tyres emit noise very much concentrated within the 1 kHz octave. Tone correction may be considered.
11. *Quiet tyres are possible only if sacrificing safety.* Recent results show that there is no tradeoff between low noise emission and high safety; neither with rolling resistance.
12. *We cannot afford to reduce tyre/road noise.* Calculation exercises are presented that suggest that low-noise tyres as well as low-noise road surfaces may be very cost efficient.
13. *Tyre/road noise will be substantially reduced by the introduction of noise emission limits.* Not true; the new EU emission tyre noise limits will be almost totally ineffective.

1. Introduction

At this conference, the subject of tyre/road noise is on the agenda to a greater extent than ever before at an Inter-Noise conference. One reason may be that it is now a long time since any conference specialized on the subject was organized [1], but a more important reason is that it has become obvious to more and more people that this type of noise now constitutes the major problem in traffic noise in (at least) the highly industrialized countries.

The term tyre/road noise denotes the noise emitted from a rolling tyre as a result of the interaction between the tyre and the road surface. In this paper, only noise emitted outside the vehicle is considered, i.e. exterior tyre/road noise. In principle, more than the tyre may radiate this type of noise, most notably structure-borne sound may spread to the rim and parts of the vehicle body and radiate from there, and possibly also from part of the road surface, but radiation from the tyre itself dominates.

This paper aims at giving an insight into the past, present and future of tyre/road noise emission in the society as well as its control. This is made by means of exploring some myths and realities related to the subject.

2. Time perspective

Myth No. 1:
Tyre/road noise has become a concern only during the last decades, say from the 1970's.

Papers and reports on this subject were very rare before about 1970, but very ambitious research programs in the US throughout the 1970's, with a few extensive projects also in the U.K., culminated in international tyre noise conferences in 1976 (San Francisco) and 1979 (Stockholm). The activities opened the eyes and ears of people and put tyre/road noise permanently on the agenda; e.g. at Inter-Noise conferences.

But this does not mean that exterior tyre/road noise was an insignificant environmental factor in earlier times. At speeds above (say) 70 km/h, tyre/road noise must have been the dominating type of noise already along the highways in the 50's but it seems that almost nobody was aware of it. Engineers in the vehicle and tyre industry were concerned with interior tyre/-road noise already in the 30's, but the first major experimental study on exterior tyre/road noise that this author is aware of was published in 1955 [2].

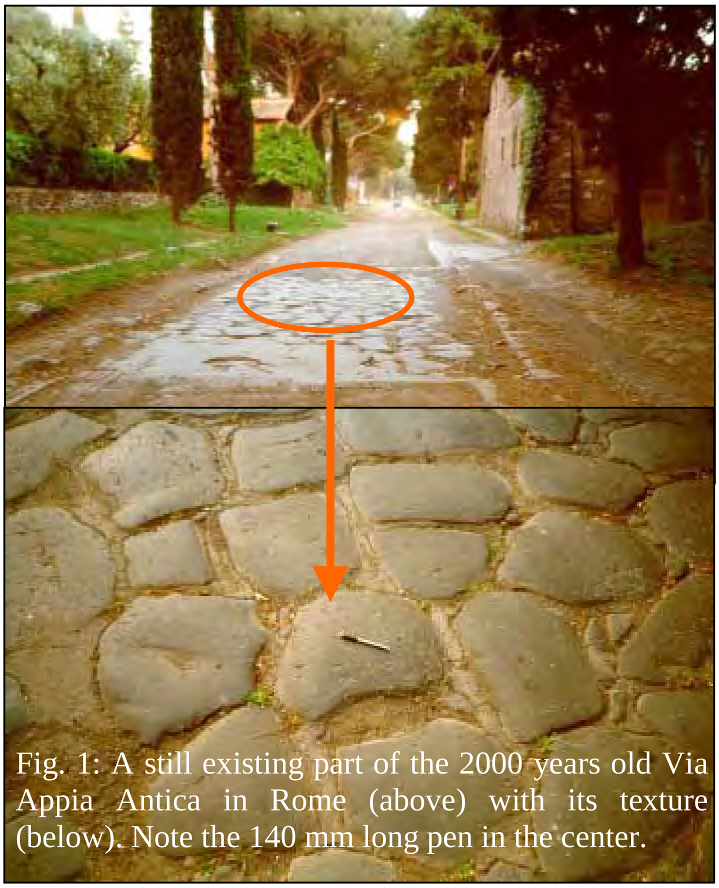


Fig. 1: A still existing part of the 2000 years old Via Appia Antica in Rome (above) with its texture (below). Note the 140 mm long pen in the center.

The term tyre was used even before the pneumatic tyre was known; representing the outer part of the wheel. In the days of iron-shrodded wheels/tyres, the interaction of metal (tyre as well as horse shoes) and stone (pavement) created noise that was of concern to many. Complaints on such traffic noise were common already in the Roman Empire. Fig. 1 may illustrate how a typical Roman pavement looked like and it is easy to imagine that the tyre/road interaction then must have created lots of noise.

Nearly two thousand years later, in 1869, the problem seemed to be more or less the same, as noted by Sir Norman Moore, a British physician, who gave a graphic description of the noise in a London street: "*Most of the streets were paved with granite sets and on them the wagons with iron-tyred wheels made a din that prevented conversation while they passed by. The roar of London by day was almost terrible - a never varying deep rumble that made a background to all other sounds*" [3].

The problems led to trials with low noise road surfaces, already in the 19^{th} century, like for example wooden block pavements that were both smoother and softer than the various stone pavements [4]. But, just as today, low noise surfaces, did not last 2000 years like the Roman pavements did. So, nothing is new under the sun, not even tyre/road noise.

3. Tyre/road noise as part of vehicle noise

Myth No. 2:
Tyre/road noise is an important part of vehicle noise at speeds above 50 km/h for cars and 70 km/h for trucks

Vehicle noise is composed mainly of tyre/road noise and noise from the powering of the vehicle, what is here called power unit noise. Power unit noise is composed of noise from the engine and all its "accessories", the exhaust system and the transmission. Both tyre/road and power unit noise have strong relationships with vehicle speed. First, one shall recognize that tyre/road noise level increases approximately logarithmically with speed (Fig. 2), which means that on a logarithmic speed scale, noise levels increase linearly with speed. Power unit noise depends on a number of vehicle operating factors, most notably the gear selection and the engine speed, and its relation with vehicle speed is much more complicated than that of tyre/road noise. At high speeds it follows almost the same noise-speed curve as tyre/road noise, but at lower speeds it levels out at a level close to or somewhat above that of idling.

To simplify things very much, one can say that at low speeds power unit noise dominates while at high speeds tyre/road noise dominates, and there is a certain "crossover speed" where the contributions are about the same. When tyre/road noise was first recognized as a problem in the early 70's, it was assumed that the crossover speed was in the range of 50-70 km/h for cars and 70-90 km/h for trucks. In the literature of the 80's and 90's, the crossover speed for constant-speed driving is often referred to as 40-50 km/h for cars and 60-70 km/h for trucks; implying that tyre/road noise dominates at all highway and motorway driving conditions and power unit noise dominates in urban driving.

We who work regularly with tyre/road noise studies, as well as all vehicle manufacturers, know that this might have been the case long ago, but that today the crossover speed is much lower. Fig. 2 shows a rather typical example of vehicle noise from a modern car at various (but constant) speeds. Measuring conditions are similar to that of ISO 362 and ISO/DIS 13325. Since we know that if one has two (incoherent) noise sources that are equally strong, the overall level will be 3 dB higher than the level for the single source, we can say that the power unit noise level equals tyre/road noise level when the overall curve is 3 dB higher than tyre/road noise; if it is less than 3 dB higher, tyre/road noise will dominate. From Fig. 2 it then follows that tyre/road noise dominates over power unit noise for all speeds and gears except when driving on the first gear. In practice, it means that at constant-speed driving tyre/road noise always dominates, even in a "Tempo 30" or congested urban situation!

Figure 2 (right):
Overall vehicle noise at constant speeds (cruise-by) for a Volvo S40 (2000) in new condition at various gears. This is the sum of power unit and tyre/road noise. The levels for coast-by (only tyre/road noise) are also indicated. Note the different vertical scales in Figs. 2-3.

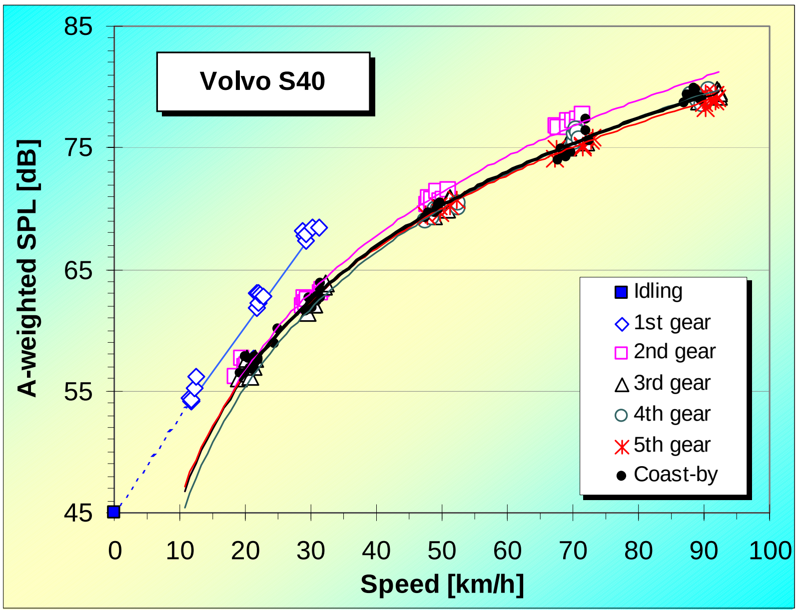
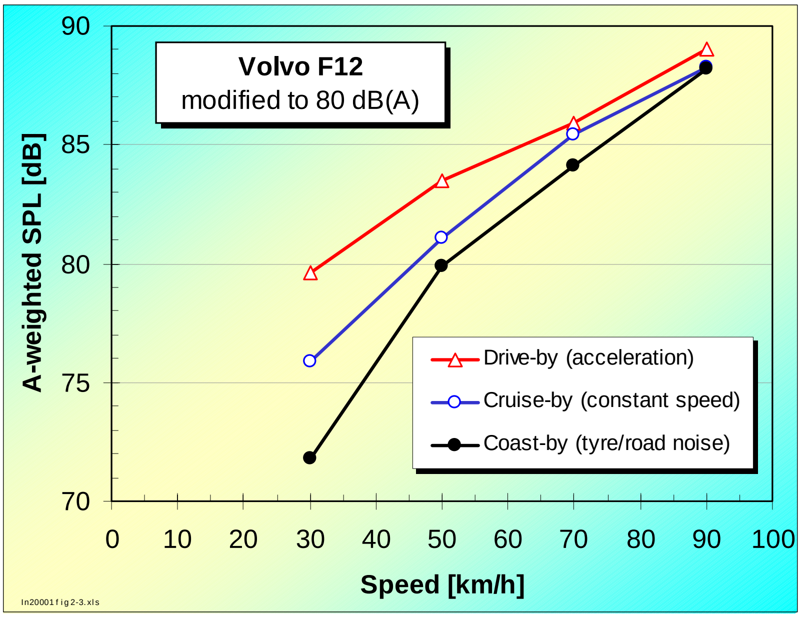


Figure 3 (lower right):
Overall vehicle noise at constant speeds (cruise-by) and acceleration (drive-by) for a Volvo F12 truck that meets the current 80 dB(A) limit. Levels for coast-by (only tyre/road noise) are also indicated.



When vehicles are under acceleration, both tyre/road and power unit noise levels increase due to the extra tyre torque and engine load; the increases are normally the highest for power unit noise. This means that at such conditions power unit noise may occasionally exceed tyre/road noise on the 2nd gear (but hardly in higher gears).

How about heavy vehicles? Corresponding data for a typical heavy truck with trailer is shown in Fig. 3. Since these vehicles have so many gears, data are not shown for each gear; instead at each speed (30, 50, 70, 90) a typical gear was selected. However, an extra curve is shown, namely for "Drive-by", which is for a "normal" acceleration mode.

It appears that tyre/road noise dominates from about 50 km/h for this vehicle, even during acceleration. One may say that power unit noise dominates during all accelerations 0-50 km/h, but tyre/road noise dominates at all driving above 50 km/h and already from about 40 km/h at constant speed. It means that even in urban driving, except in congested traffic or if the posted speed limit is 30 km/h, tyre/road noise dominates for a heavy truck with trailer.

For vehicles of intermediate sizes, the situation is somewhere in-between of the described cases. Since most of today's vehicles are designed to emit noise levels that are 1-2 dB below the legal limits, there is not a great spread between them; therefore the data for the selected vehicles in Figs. 2-3 are believed to be "typical" for most countries in Europe and for Japan. In countries, where legal noise emission limits are more liberal, such as in the USA and many African and Asian countries, the situation may be quite different.

4. Noise reductions achieved so far

Myth No. 3:
Manufacturers have done a lot to reduce vehicle and tyre/road noise

Acoustic engineers have worked in the vehicle and tyre industries in many decades with the aim to reduce or at least limit noise. The acoustic environment within the vehicle cabins is an important commercial argument: vehicles that are quiet inside are considered comfortable and give the owner a feeling of luxury. One of the most common arguments in advertisements for new vehicles is quietness. Not only objective measurements, but advanced subjective evaluations are commonplace and the sound from each little component may be devoted lots of efforts. This author thinks that the success in reducing interior noise in vehicles in the past decades has been remarkable. Ref [5] found that in the time period 1976-85, interior noise levels in 1.5-1.8 l cars in Japan driven at 100 km/h had decreased by 8 dB(A), which is a good illustration of this progress; something that is still going on.

This progress regarding interior noise is probably a combination of vehicle and tyre efforts (remember that the 8 dB(A) reduction mentioned above was at 100 km/h when tyre/road noise dominates).

With regard to exterior noise, the comfort and luxury argument is much weaker since it does not so much influence the vehicle owner. Instead, many governments have agreed on regulations and directives that limit the maximum noise emission levels from vehicles. When the system for this was first developed, in the 60's and early 70's, there was still no tyre/road noise in the minds of the responsible people; thus they designed a system that would take care of, predominantly, power unit noise. The measuring method ISO 362 and its relatives in the regulations and directives are governing this. The emission limits introduced first in the 70's were very liberal, but later tightenings of limits have been rather tough, at least for trucks and busses. For example, since first introduced 30 years ago, the limits for the heaviest trucks are now (effectively) about 15 dB(A) lower than originally. For cars, the effective reduction in limit is less than half of that for heavy trucks. See further [6] and [7].

In real traffic, though, the vehicle noise levels have not been reduced so much. Fig. 4 obtained from reference [8] is probably the best illustration of that.

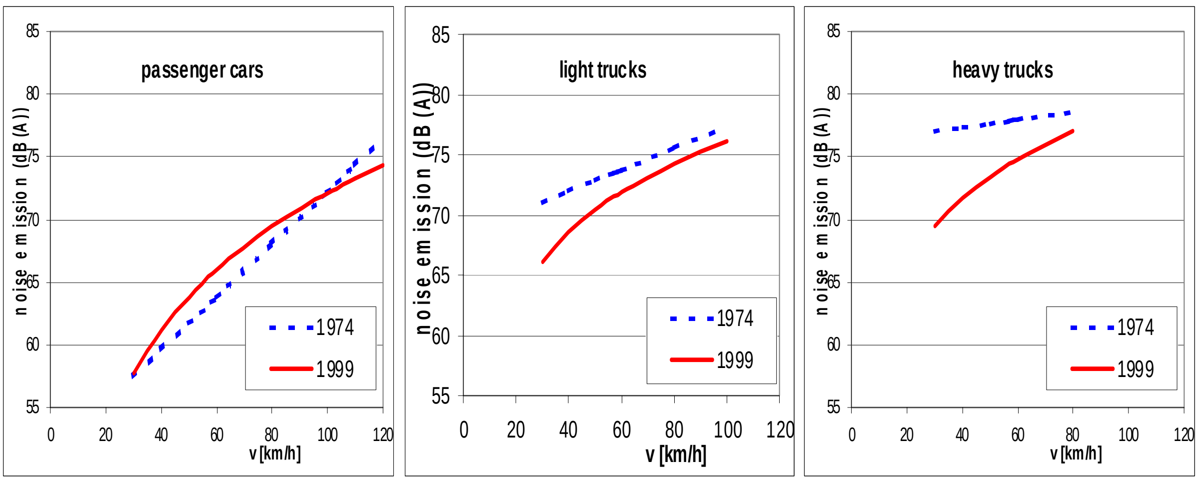


Figure 4: Comparison of noise emission measurements made in 1974 and 1999; based on hundreds of measurements on individual vehicles driving in normal traffic in the Netherlands. Figure from [8].

So far, no direct limits for tyre/road noise have been in effect. This probably explains why there seems to have been no significant noise reduction at the higher speeds where tyre/road noise dominates. The noise of trucks has decreased significantly at lower speeds. The noise of cars has *increased* slightly at medium speeds.

Consequently, the tyre and vehicle manufacturers have been successful in reducing interior vehicle noise. Exterior vehicle noise has been reduced almost nothing at high speeds (tyre/road noise) but substantially at low speeds for heavy vehicles. To meet legal requirements, however, the vehicle manufacturers have had to make much higher noise reductions than can be noticed in real traffic. Although, not totally conclusive, there is evidence that suggests that exterior tyre/road noise of car tyres may have increased somewhat rather than decreased [7]. The reasons for the latter are thought to be a combination of no requirements being in place and a general trend toward wider tyres with optimisations more and more focussed on extreme high-speed performance.

5. Speed influence

Myth No. 4:
The speed influence is large but not very interesting

No other single factor has such a prominent influence on tyre/road noise as speed. It is well known that the noise relationship with vehicle speed very closely follows the ideal relation:

$$L = A + B \cdot log(V)$$

where L = Sound Pressure Level (SPL) in dB, V is the speed in km/h and A, B are speed coefficients (constants). The curve for "coast-by" in Fig. 2 is a good example of this. On top of this relation, there is often a "fine structure"; at least if the surface is smooth and the tyre has a non-randomized pattern. Curves according to the equation are frequently presented; often one curve per tyre/road combination, which can make such a diagram quite messy. Apart from that, one seldom looks any further into the noise-speed relation.

When plotting the A and B constants in an x-y diagram against each other, it appears that the point (A,B) created for each tyre/road combination always deviates very little from a regression line. See Fig 5. At the Technical University of Gdansk (TUG) in Poland, the researchers have collected 1700 such data points (i.e. tyre/road noise combinations) and found that the deviation from a regression line in general is very small. This author and Prof. Ejsmont at TUG have looked closer at this and found that the deviations from this regression line are quite interesting in order to, in an extremely condensed form, present noise characteristics for a large number of tyres, or road surfaces, or combinations of them.

In Fig. 5, the line is assumed to be the regression line of A versus B for a large number of measurements (or any other reference line that one would prefer). Any point there represents the coordinates A and B describing the tyre noise-speed equation. A point deviating perpendicularly to the line represents a different noise level for that tyre in relation to an "average" tyre. Deviation toward lower left means that the tyre is "quieter"; deviation toward upper right means that the tyre is "noisier". The further left the point is located, the lower its slope is; which means that this tyre is more favourable at higher speeds and less favourable at lower speeds. The contrary is the case if the point is located more to the right.

The figure can be useful for selection of tyres or road surfaces. Points A, B, C and D are examples of tyres (or road surfaces) that display different characteristics in terms of noise level at low and high speeds. A tyre or road surface that gives a point near C should be chosen for a low-speed case (in such a case a tyre near point B must be avoided), whereas a tyre or road surface near point A should be chosen for a high-speed case (and a tyre near point D should be avoided). An all-round tyre should be chosen from the middle of the *B* scale, with as much deviation lower-left from the reference line as possible.

The advantage with such a point diagram, compared to the traditional diagram with curves, is that it allows many more tyre-road combinations to be plotted without making up too messy a diagram. Using noise-speed curves, one may possibly accommodate about 10 cases (curves) in the same diagram, but with a point diagram, one may accommodate perhaps some 10 times more cases with no problem. After a while, most users of such diagrams will become familiar with the interpretations of them.

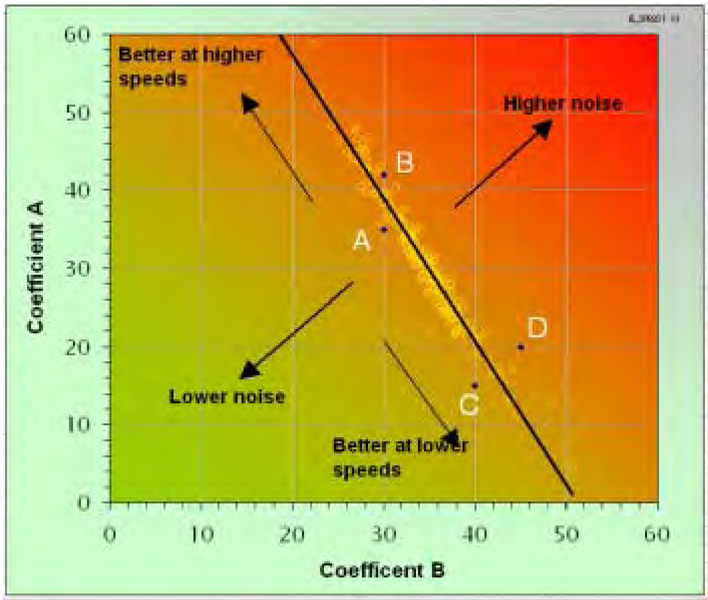


Fig. 5
General relation between the speed coefficients *A* and *B*. Each circle symbol is one such point (*A*,*B*), i.e. one tyre/road combination. The white letters A, B, C and D denote tyres with special characteristics, see the text. The arrows attempt to explain the characteristics of the position of a point in the diagram.

6. Road surface influence

Myth No. 5:
Different road surfaces may give a large variation in noise levels; and the coarser the texture, the higher the noise emission becomes

There is no doubt that the first line of the statement above is true. See for example Fig. 6, which shows a range of 17 dB(A) between the most "quiet" and the most "noisy" surfaces that have been measured. This is expressed as levels of CPXI (Close Proximity Index) according to ISO/DIS 11819-2, measured with the TUG trailer. It seems to be an incredibly large range, but then one shall not forget that the end points are indeed extreme surfaces that are not interchangeable. If one would limit the surface types to such that are safe surfaces for more general use, the range shrinks to 9-11 dB(A). The surfaces that are on the "quiet" side will probably also become less efficient after some wear and the most "noisy" surfaces among the remaining would probably not be considered in a noise-sensitive situation. But, in principle even a range of (say) 7 dB(A) is still a rather large range. So, the first part of the "myth" can be confirmed to be valid.

Fig. 6 also indicates the texture of each surface (the red diamonds connected with a line) with the Mean Profile Depth (MPD) as measured with the ISO 13473-1 method on the scale to the right. The MPD has been found to be a good measure of surface texture for describing influence on wet friction. Note also that each bar contains a photo (common scale) of its texture. It appears that the relation between CPXI and MPD is far from clear; one can imagine a relation only when the surfaces are very rough. Thus, the last part of the "myth" can be rejected. See [4] for more information about surface influence on tyre/road noise.

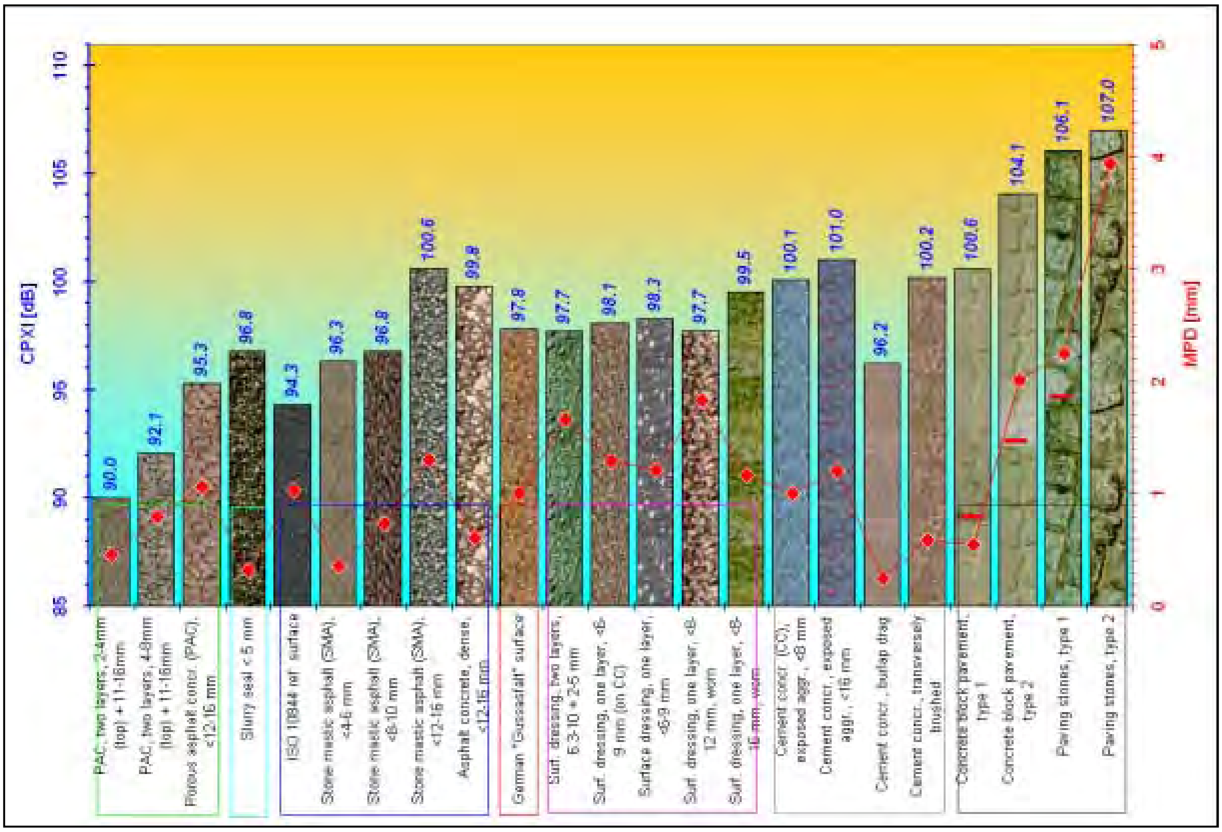


Figure 6: Tyre/road noise level on various road surfaces, expressed as CPXI (see ISO/DIS 11819-2) measured with the TUG trailer at 80 km/h. Also indicated is the texture of each surface, expressed as MPD (see ISO 13473-1) and indicated by red diamonds connected by red lines.

7. Tyre influence

Myth No. 6:
Tyres do not differ very much in noise emission

Many tyre/road noise studies have indicated that the difference in noise emission level between different tyres is very small. For example, in the large EU project TINO under the leadership of Pirelli [9], the conclusion was that the difference between the best and the worst tyre was only 3 dB(A). One of the main project goals was to construct a prototype tyre with lower noise emission. The result was a tyre about 1 dB(A) less noisy than a reference tyre [9], the latter of which was a tyre somewhat noisier than the average. Pirelli and TINO concluded that one cannot obtain much noise reduction by working on the tyre; instead one should work on the road surface.

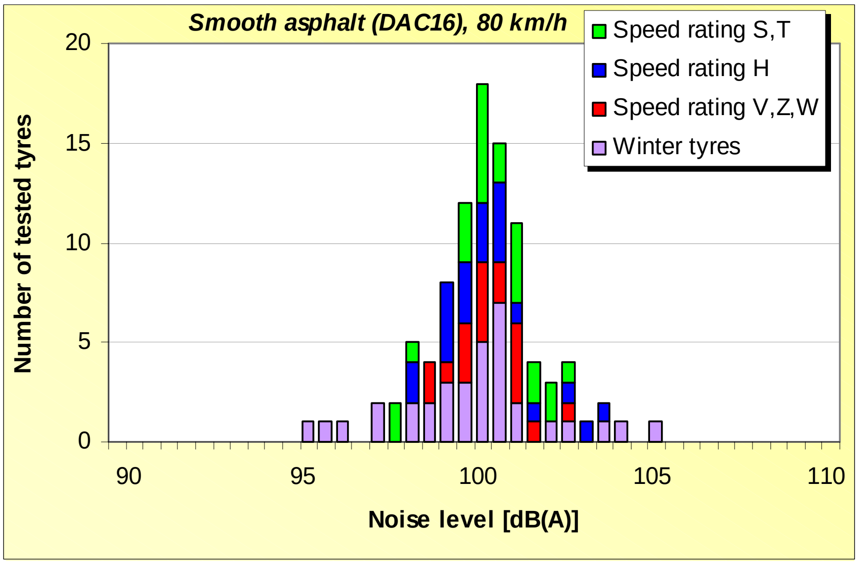
Our studies have not been able to confirm this. For example, our most recent study on the difference in noise between various tyres is presented in Fig. 7. This indicates a range of 10 dB(A) between the best and the worst tyre in a sample of nearly 100 tyres of approximately similar sizes (the tyres were all new or newly retreaded and available in tyre shops). For truck tyres, a study indicated a range of 10 dB(A) between the best and the worst of 20 tyres of similar size, measured on a surface that had similarities with an ISO surface, and 8 dB(A) on another smooth surface [10].

Data from other studies show for instance the following. Measurements in 1992-93 by TRL, UTAC and FIGE showed a range of 9 dB(A) for car as well as for truck tyres [11]. A study by TRL including 23 car tyres on an HRA and an ISO surface showed a range of

5 dB(A) [12]. Finally, measurements in Germany indicated a range of 6 dB(A) between the best and worst of 48 tyres of approximately similar sizes [13].

Thus it appears that if one includes a large number of tyres, one may get a range of about 10 dB(A), but when limiting the number to (say) less than 10, it is common to get a range of only 3-4 dB(A). In many cases, studies also concentrate on fairly similar tyres. In addition to the ranges quoted above, one shall keep in mind that other variables like tyre width and state of wear also affect noise levels and will increase the range. When taking all such effects into account, it seems that the range for tyres is approximately as large as for road surfaces.

Figure 7:
Distribution of noise levels for a test sample of almost 100 tyres, refer to [14] for further information. Measurement at 80 km/h with the CPX method on a dense asphalt concrete with max 16 mm chippings. The speed rating of the summer tyres is indicated according to three classes.



8. "Winter" versus "summer" tyres

Myth No. 7:
Winter tyres are much more noisy than summer tyres

In countries where people change from the normal "summer" to "winter" or "M+S" tyres in wintertime, the traditional experience is that this leads to higher noise levels. The main reason is the "more aggressive" tyre tread that winter tyres need to have in order to carry away or penetrate slush and snow. The "all season" tyres are in an intermediate situation, with somewhat higher air/rubber ratio in the tread pattern. So, this is what one would expect, and what was a fact some time ago.

However, Fig. 7 shows that this is no longer the case. The quietest tyres are found in the "winter" group and not even the average level is higher than for "summer" tyres. If one would fit studs into the tread pattern, which is common in Sweden, Norway, Finland, Iceland, Canada and parts of Russia and USA, studs are generally increasing the noise emission by about 3-6 dB(A). It will then be possible to find certain studded winter tyres that are less noisy than normal summer tyres! The reasons are believed to be that "winter" tyres generally have softer rubber compound than the "summer" tyres and that their tread patterns are crossed by narrow sipes, giving a lamellae-like pattern; all making the tread block impact and footprint movements smoother. The tread patterns are also much more elaborated than in earlier times; not the least with the intention to reduce noise emission (and especially interior noise).

9. Influence of tyre width

Myth No. 8:
The width of the tyre is a very influential factor

It has been an almost continuous time trend during the latest century that tyre widths have become larger, especially on cars. It is generally assumed that this is one of the main reasons why tyre/road noise has not been reduced with time; and possibly increased instead. So, one should carefully study the width influence on noise.

Fig. 8 shows a compilation of data that this author has made. The main part of the data comes from measurements made by the three research organizations TRL in the U.K., UTAC in France and FIGE (now TÜV Automotive) in Germany as preparations for the EU Directive on tyre noise, see Chapter 14. Also data from a recent TRL study ("TRL 2001") have been included [12]. A total of 276 tyres are included, of which 47 are van and truck tyres. The data in the figure have been normalized to represent the measuring conditions of coast-by at 80 km/h (if speed was 70, a correction of +2.0 dB was applied) on an ISO surface with a 4-wheeled vehicle with a wheelbase around that of a car (for a wheelbase of 6.0 m, a correction of +0.5 dB was applied). In the figure, not only data for car tyres but also for van and truck tyres are included. Finally, also a measurement made by this author on a competition bicycle with very narrow tyre has been included (normalized to 80 km/h with speed coefficient *B* = 35 and to four wheels rather than two). Note that the 385 mm tyres are all tyres for truck trailers, and as such have a rather uniform type of pattern similar to that of the truck tyres at 305-315 mm below the regression curve. Therefore, the rightmost part of the curve probably is biased towards a lower level than would be "typical" without this bias.

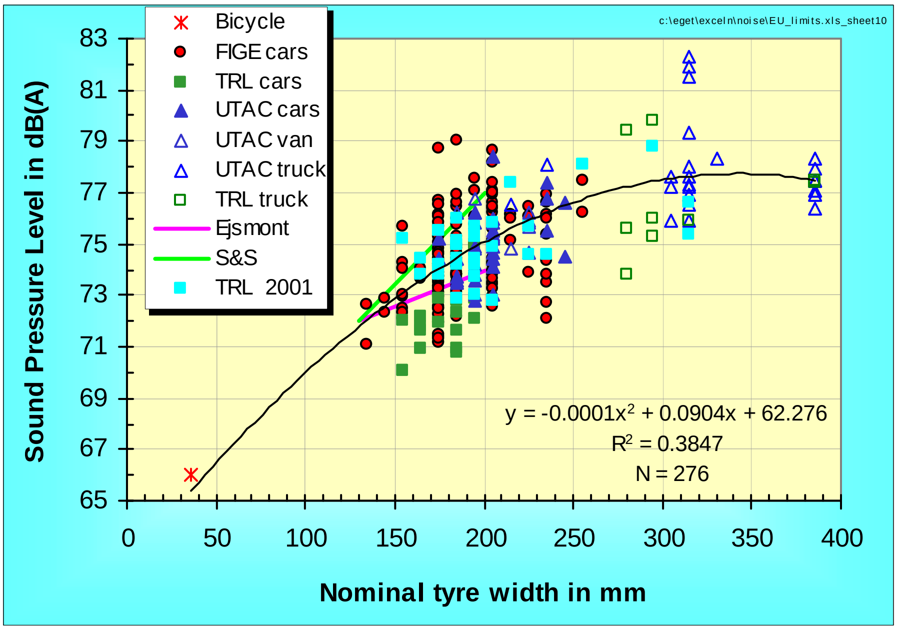


Figure 8:
Relation between noise and nominal tyre width, for a full range of tyre sizes. Data have been compiled from several sources and normalized to represent uniform conditions (see text).

Note: Just for curiosity it can be mentioned that if the width scale is logarithmic, the regression turns linear.

First, a regression analysis using only the car tyre data was made and then another one was made for all tyres (the latter shown in the figure). It looked like a polynomial line rather than a straight line was motivated, since for car tyres wider than 200 mm, noise levels are not increasing so much; a trend that is strengthened when truck sizes are included. Actually, the truck and bicycle data fitted an extrapolation of the car data very well. It thus looks as if the noise-width relationship is rather general and not limited to just one class of tyres. It would be interesting to see where super-single tyres would fall in the figure, but such data are not yet available since it is very difficult to test those wide tyres according to the EU Directive. We have also tried to get access of motorcycle tyre noise data but failed so far.

The green line drawn from 72 to 77 dB denotes a relation reported in [15], based on measurements in Sweden and Norway in the 70's and 80's on a great number of car tyres. Since tyres wider than 200 mm were rare then, the relation was then limited to the extent of the green line, and one may easily imagine that a quite similar conclusion would have been made if the same restriction of range would apply to the data in Fig. 8.

Apart from tyre width, the figure includes variations like tread pattern, rubber hardness, load and summer/winter tyres. It could well be that some of these may have a co-variation with width; in particular load has such co-variation. Therefore, the curve in the figure probably exaggerates the width influence if one would consider purely the width.

Attempts have been made to study a pure width influence on tyre noise, most notably by Ejsmont in Poland [16]. He obtained a relationship following the violet line from 72 to 74 dB in the figure. This is only half the slope of the "raw" curve.

Consequently, the "myth" has a solid background, but when looking closer at a *pure* width influence, the tyre/road noise emission is only "half as much" influenced by width as generally assumed.

Nevertheless, one can say that a change from 155 mm to 195 mm tyres would mean almost 2 dB(A) of noise increase. This may be a typical trend in the use of tyres on a mid-to-full-size car from the 1960's versus a similar car of the 1990's. Over such a time span, of course also a lot of other changes have occurred to tyres.

It is suggested that a major part of the width influence may be due to the horn effect being "short-circuited" at the contact-patch edges when the tyre is narrow (being totally eliminated at widths below about 50 mm) and that the horn effect reaches an upper level at around 200 mm width when the "short-circuiting" effect becomes insignificant.

10. Truck versus car tyres

Myth No. 9:
Tyre/road noise from a heavy truck is far above that of a typical car

Reflecting a lot of measurements, traffic noise prediction methods assign approximately 6-10 dB(A) higher noise emission levels to heavy trucks than to typical cars. Often, a rule-of-thumb saying that a heavy truck is 10 dB(A) "more noisy" than a car is used. The heavy load carried by a truck compared to that of a car also makes it natural to think along those lines.

However, looking at Fig. 8, one may find a heavy truck having four 315 mm wide tyres that actually emits a lower tyre/road noise level than a mid- or full-size car (a truck with four 385 mm tyres would do the same but steering tyres would not usually be that wide). This is quite remarkable. It means that the reason for trucks generally emitting higher tyre/road noise levels than cars is not so much the increased loads and the larger tyres, but that the NUMBER of tyres is higher. For example, 16 wheels of a typical tractor-semitrailer combination give 6 dB higher noise levels than a reference four-wheel vehicle.

One possible reason why truck tyres seem to emit lower noise levels than expected from their width and load, and also their higher stiffness, may be that the diameter is 50-100 % larger than for car tyres. This diameter difference should give a softer impact and release at the leading and trailing edges of the contact patch. It has not been possible to establish a clear effect of diameter influence on noise for the car range of tyres, but maybe this effect is important when comparing tyres of such different diameter as truck and car tyres.

11. Spectral features

Myth No. 10:
Tyre/road noise is very broadband nowadays, due to efficient tread pattern randomization

Tyre manufacturers nowadays employ very advanced methods to make sure that tread patterns are properly randomized, in order to avoid tonal components. It follows that tyre/road noise spectra show broadband characteristics. Or, can this statement be challenged?

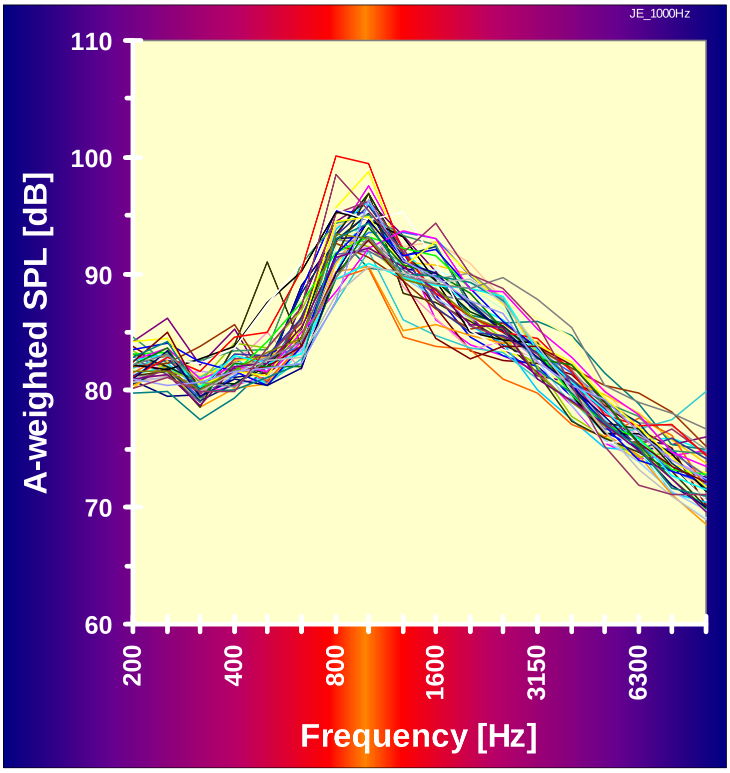


Figure 9:
Third-octave band spectra obtained by Prof Ejsmont and this author for 50 different car tyres running on the TUG drum with an ISO replica road surface at a speed of 90 km/h [17].

Figure 9 shows a compilation of A-weighted third-octave band spectra for 50 different car tyres tested recently in a Swedish-Polish co-operation project [14]. The measurements were made with the CPX method on a laboratory drum covered with a replica of an ISO 10844 surface. Similar results are obtained on other fairly smooth surfaces. Narrow-band spectra do not reveal any special features in this case, so it is justified to say that randomization has been successful. However, can one say that the 50 spectra are of broadband character? One or two third-octave bands at 800-1000 Hz usually dominate the emission. Listening to this, one cannot distinguish tones, but one can hear a pronounced "colouring" of the sound. For an average spectrum in the figure, approximately 70 % of the A-weighted sound energy is produced within the 1000 Hz octave. One can also say that if the peak were not there (if the 1000 Hz octave had the same level as the octaves surrounding it), the overall level would be reduced by approximately 6 dB.

The remarkable spectral peak can been noticed also in several other investigations and its occurrence and causes are discussed extensively in [17]. It is caused by several modern tyre features and some road surface features in combination, such as A-weighting (i.e. human sensitivity to sound), the so-called horn effect, tyre tread block size, air resonances in longitudinal "pipes" in tread, air resonances in lateral tread grooves closed at the inner end, Helmholtz resonance in air cavities, belt resonances, tangential block resonances, average spacing between road surface chippings and texture-sound transfer properties of the tyre. All these factors can be shown to have a certain influence in the 1000 Hz octave, and in combination they seem to cause a prominent but rather broad spectral peak.

Comparison of average vehicle noise spectra from the 70's with those of the 90's suggest that this spectral peak is a rather late phenomenon [8,7]. It seems to this author as if the task to *separate* or displace these features in the frequency domain is currently one of the most important challenges for tyre constructors.

In two of the spectra in Fig. 9, the peak third-octave has a level more than 5 dB above that of any adjacent band, in which case a tone adjustment K_1 based on third-octave band detection according to ISO 1996-2 may be made (although ISO 1996, currently under revision, refers to environmental noise assessment based on L_{Aeq}). In such cases ISO 1996-2 states that the overall level should be increased by 5-6 dB to account for increased annoyance. This might become a common situation if there is such a time trend of spectral concentration and if this continues. Of course, in this case it is not likely to be a pure narrowband component in the spectrum, rather a fairly "broad but pronounced peak". The assessment of such "semi-narrow-band" sound may be worth putting on the agenda in the near future.

12. Low noise compromising safety?

Myth No. 11:
Quiet tyres are possible only if sacrificing safety

Behind the proposal in 1997 by the U.K. Department of Environment, Transport and the Regions to the EU Commission and to the ECE/GRRF to introduce requirements on friction characteristics of tyres was a fear that limiting tyre/road noise would cause a switchover to tyres with lower safety. Although no study has yet clearly demonstrated such a conflict, it has been a rather common assumption in discussions over the years that it does exist. Perhaps such prejudice is fuelled by numerous papers from tyre manufacturers pointing out (correctly) the many performance parameters that need to be considered when constructing a new tyre and that compromises and optimizations are necessary. It is then common by readers or listeners to assume that most parameters are in conflict, among them low noise and high safety, but this is not necessarily the case.

Recently, a couple of studies have investigated this problem. In our own study, presented at Noise-Con 2000 [14], results from measurements on almost 100 car tyres were reported. The measurements included tyre/road noise emission with the CPX method, both in the field on three road surfaces and in the laboratory on three drum surfaces (replicas of road surfaces), wet friction on one road surface with locked wheel and at optimum slip, as well as rolling resistance in the laboratory on two surfaces. An example of the results is shown in Fig. 10. It shows the relation between tyre/road noise tested on a dense asphalt concrete road surface (max 16 mm chippings) and friction coefficient measured on a similar type of surface. Each point in the diagram represents one tyre.

There is no statistically significant relationship between noise and wet friction according to these results. The same goes for the other noise measurements evaluated against the two friction parameters.

Fig. 11 shows a similar comparison between noise and rolling resistance measurements. In this case, tyre/road noise was measured on a rather rough-textured chip seal road surface while rolling resistance was tested in a laboratory with the same type of surface on the drum. A weak relationship can be seen here, statistically significant on the 5 % risk level, fortunately indicating that low noise and low rolling resistance go hand in hand. Also these results are typical of the other relations found when comparing noise and rolling resistance.

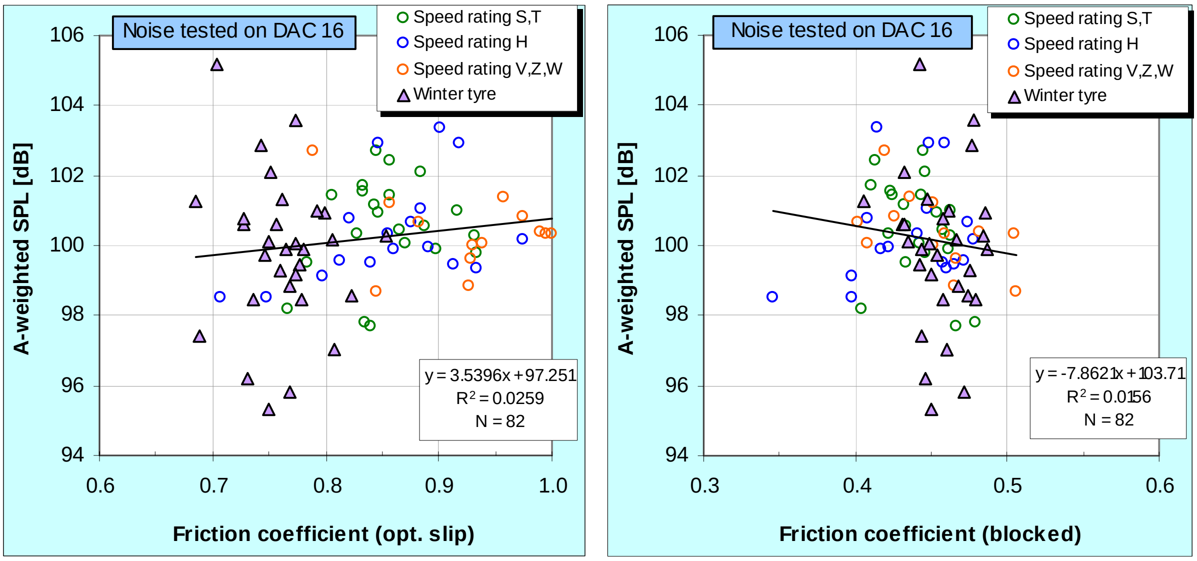


Figure 10: Correlation between tyre/road noise measured with the CPX method on a dense asphalt concrete road surface (max 16 mm chipping size) and friction coefficients of tyres measured either at optimum slip (left diagram) or blocked wheel (right diagram). Friction measurements at 70 km/h, CPX measurements at 80 km/h (see further [14]).

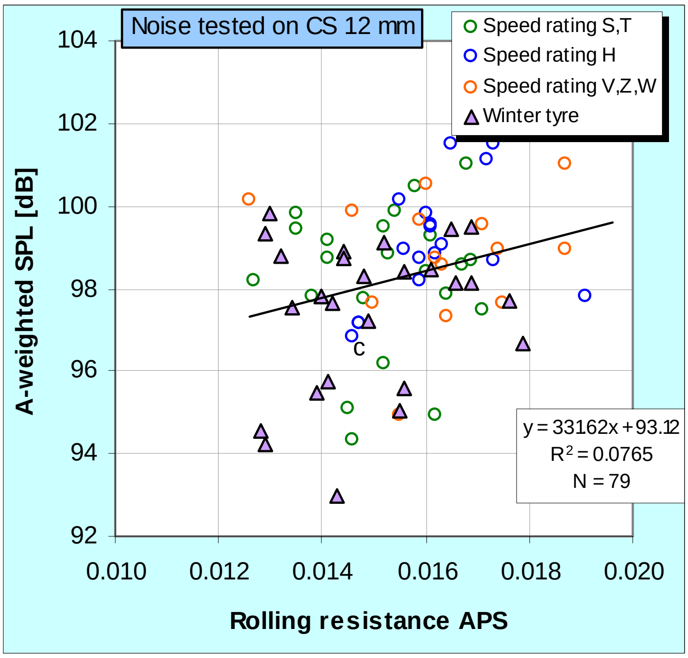


Figure 11: Correlation between tyre/road noise measured with the CPX method on a chip seal road surface (max 12 mm chippings) and rolling resistance of tyres measured on a similar rough-textured surface. Speed 80 km/h (see further [14]).

Essentially the same results were reported in the other recent study on this subject [13]. TÜV in Germany tested 48 tyres but using the coast-by tyre noise measuring procedure and also testing hydroplaning characteristics. Measurements were only made on one surface.

These two studies, made totally independently and with several differences in design, arrived at the same conclusions: there seems to be no conflict between requirements of low noise and high friction, and if there are any relations between noise and rolling resistance at all, they are weakly positive (i.e. no conflict). These two studies should then provide rather safe indications. In this light it is a mystery why the EU Council and the Parliament in their recent decision refer to making a study of this matter and after three years issue a report, based on which a slight lowering of noise emission limits for tyres might be considered, should the report show that this can be made without compromising safety [18].

13. Costs & benefits of low noise tyres and road surfaces

Myth No. 12:
We cannot afford to reduce tyre/road noise

A recent Swedish study estimated the current road traffic noise damage costs in Sweden [19]. The total was USD 330 million per year. This included only costs associated with housing, mainly based on depreciation of residential homes; thus it is likely to be an underestimation. The study also calculated the noise damage costs as expressed as average cost per vehicle km, arriving at a value for light vehicles of USD 0.001 per km in extra-urban driving and USD 0.009 per km in urban driving. Corresponding values for heavy vehicles was estimated at 0.005 (extra-urban) and 0.06 (urban).

Considering the traffic work in urban and extra-urban areas and the number of vehicles in Sweden, this author calculated the corresponding average cost per vehicle and year at USD 63 for light and USD 630 for heavy vehicles. This was calculated for Sweden, in which only 15-20 % of the population is exposed to L_{Aeq24h} exceeding 55 dB, according to [19]. Most European countries and Japan (for example) have noise exposures that are more than double that of Sweden; for example the average in Europe was 66 % according to the EU Green Paper in 1996. It means that the corresponding noise damage cost per year for a vehicle in an "average" European country most probably is more than double that of Sweden.

The following shall be regarded as an arithmetical exercise and a discussion. Assume first that the noise damage cost for a European average car is USD 126 per year, i.e. double that of a car in Sweden. A value indicated in the Green Paper can be shown to correspond to around ECU 105 per year, but this was now almost 10 years ago; thus the value assumed above is reasonable as a lower limit. Assume that the external costs of noise from an average light vehicle is, proportionally, 30 % on power unit noise and 70 % on tyre/road noise (considering chapter 3 above). This gives a tyre/road noise cost per vehicle of approximately USD 90 per year. With four tyres per car and assuming that each tyre will last four years, this gives USD 90 per tyre.

This author has also calculated that in order to obtain a halving of the noise damage costs in Sweden, the noise level distribution needs to be pushed down by 3.5 dB.

Next, assume that all car tyres become 4 dB less noisy. This would then correspond to more than a halving of noise damage costs, i.e. correspond to a saving of more than USD 45 per tyre. An average car tyre in Sweden costs about USD 90. Consequently, if tyre/road noise can be reduced by 4 dB at an increased cost per tyre of 50 % or less, this would be good economy for society. The author thinks that so many noise damage effects have been neglected in this calculation that it probably is a rather significant underestimation.

When reducing power unit noise of vehicles in the latest decades, based on the ISO 362 procedure and the EU Directive and ECE Regulation, a 4 dB noise reduction has most certainly been achieved at much lower cost increases than 50 %. For example, one heavy vehicle manufacturer has calculated the cost increase for the exterior noise reduction at < 2 % of the vehicle purchase cost (extra vehicle use and maintenance costs are additional). Although the tyre may already be the world's most advanced mechanical component, it is natural to expect that also tyres may be acoustically improved at a reasonable cost increase.

This was only an example or exercise; the world is much more complicated than that, but it suggests that one may accept very high tyre cost increases before the costs exceed the benefits. An extra benefit would be that the burden would be shifted from the suffering and "innocent" to vehicle owners that really produce the pollution – the Polluter Pays Principle.

How about costs and benefits of low noise road surfaces? This author has explored two approaches:

1. Comparing the costs of using low noise road surface in relation to building a noise barrier
2. Calculating costs and benefits of a low noise road surface in relation to that of a noise barrier, using monetary evaluation of noise exposure

In the first case, the following assumptions were made:

- The average noise reduction of a noise barrier over time and place is 7 dB(A). In [20] it is stated that the most common insertion loss is 5-12 dB(A). The average of this is 8 dB(A) but here a slightly lower value has been used since the barrier is a low-cost one.
- The average noise reduction of a low noise road surface is 5 dB(A) during its first two years and 3 dB(A) during its next two years. This assumes the use of something like the Duradrain surface reported in [21].
- The low noise road surface costs USD 5 per m^2
- Two-lane highway with a paved width of 10 m.
- The noise barrier costs USD 500 per m (one side of the road); lifetime is 20 years
- Road length considered is 200 m

This gives a cost of USD 10 000 per repaving, compared to a USD 100 000 noise barrier cost. If interest rates were neglected, it appears that one may repave the road each second year and still not exceed the noise barrier cost. In this way one may maintain a noise reduction of 5 dB(A) during the entire time. The noise barrier gives a little higher noise reduction, against which one may consider the advantage of the surface not creating any visual obstruction or impaired aesthetic effect, and also noise reduction on both sides of the road. However, if the repaving is made each 4th year instead of each second year, the low noise road surface alternative appears as only half as expensive as the barrier, while reducing noise by only 4-5 dB(A) compared to 7 dB(A). This appears as more efficient expressed as USD/dB(A). Note that if considering annuities and an interest rate of 3 %, the low noise road alternative would be about 20 % more cost-effective than when neglecting interests as was done above.

The previous example considered a two-lane highway with 10 m paved width and a noise barrier on one side of the road only. If the barrier is needed on both sides, the low noise road alternative becomes double as efficient, in which case also a four-lane motorway with 20 m paved width would find the low-noise surface alternative to be favourable.

The other approach makes use of the Swedish monetary evaluation of noise exposure [22]. A case with road traffic noise exposure along a 1 km long road (9 m paved width) through an urban residential area is studied. Four alternatives are considered: Reference case with an SMA16 surface (repaving each 7th year), replacing the SMA16 with an SMA8 (stone mastic asphalt with maximum 16 or 8 mm chippings), replacing the SMA16 with a porous asphalt (Duradrain, see above), and building noise barriers on both sides of the road. SMA8 is assumed to reduce noise by 2-3 dB(A) relative to SMA16 [23]. The barrier cost is assumed to be the same as above. The repaving cost is assumed to be SMA16 each 7th year at USD 4 per m^2, SMA8 each 5th year at USD 3.5 per m^2 and the Duradrain each 3rd year at USD 6 per m^2.

Thus, the benefit is reduced noise exposure of residents calculated as a monetary value. The costs are those of repaving and/or building of noise barrier. Simple calculations are presented in [23], resulting in the following (benefits and costs are per 20 years):

- **SMA16 → SMA8** Benefit (reduced noise exposure): USD 370 000, cost USD 18 000
- **SMA16→Duradrain** Benefit (reduced noise exposure): USD 720 000, cost USD 270 000
- **Noise barrier only** Benefit (reduced noise exposure): USD 900 000, cost USD 1000 000

It follows that the noise barrier alternative is not profitable, whereas both repaving alternatives are highly profitable. Note that this is even when repaving takes place each 3rd year!

14. Direct and indirect tyre noise limits in the EU

Myth No. 13:
The recently decided EU tyre noise emission limits will give Europe lower traffic noise

A working group called ERGA-NOISE under the EU Commission, containing perhaps the best experts in Europe, worked out a measuring method for tyre/road noise during 1992-95. The intention was to produce an amendment to the existing EU Directive for tyres, 92/23/EC, establishing noise emission limits for tyres. The working group never had the opportunity to decide on the limits, but two years after the last meeting of the group the Commission proposed the full amendment text including noise limits.

The aim is expressed as follows: "*The proposal for a directive aims to limit the rolling noise of tyres on road surfaces. In parallel with the measures already taken to limit other sources of noise caused by the mechanical parts of vehicles, these new requirements, whilst not sacrificing the tyres' grip, will help to reduce the noise emission of road traffic*" [24].

Nothing of importance happened until the European Parliament in a "second reading" in September 2000 decided to require a lowering of the limits for car tyres by 2 dB. This was then subject to a conciliation procedure, i.e. a kind of negotiation between the Council of the EU and the Parliament, which resulted in a final agreement just a few weeks before this is written. Essentially, the agreement means that the Parliament retires from its previous decision and accepts the proposal from the Commission, at least with regard to noise limits for the coming few years. The Directive is not yet published but according to private communication, it will require new tyres to meet the limits indicated in Fig. 12.

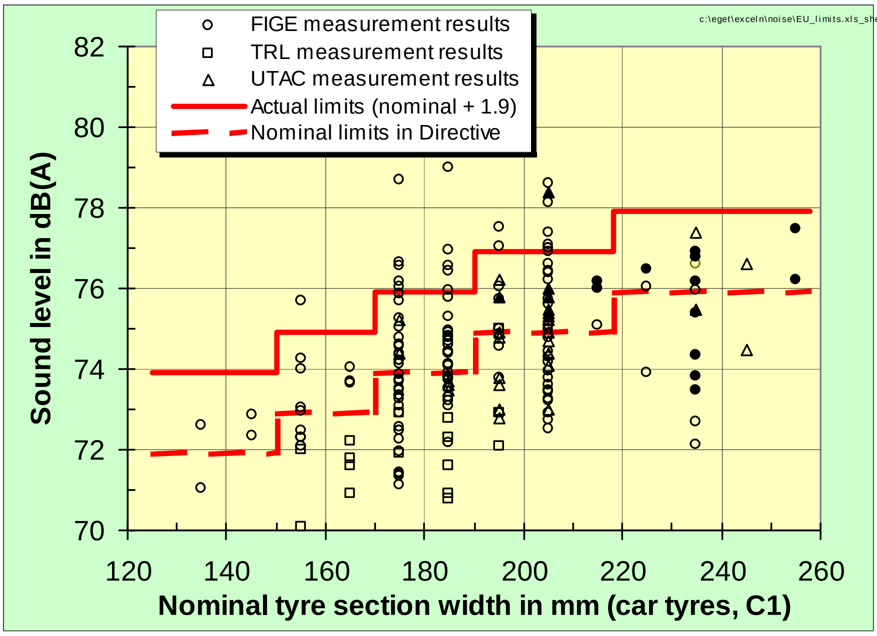
For car tyres (class C1), the limits depend on tyre section width, see Fig. 12, and measured values are normalized to 80 km/h. Reinforced tyres are allowed one extra dB and "special" tyres (e.g. for off-road use) are allowed two extra dB. For van tyres (class C2), the reference speed is also 80 km/h, but the limits do not depend on speed, rather on the use of the tyres: "Normal", "Winter" and "Special". The same goes for truck tyres, but the reference speed is then 70 km/h. "Special" tyres are e.g. tyres for use on trucks partly driven off-road, for example trucks carrying building construction material, like gravel.

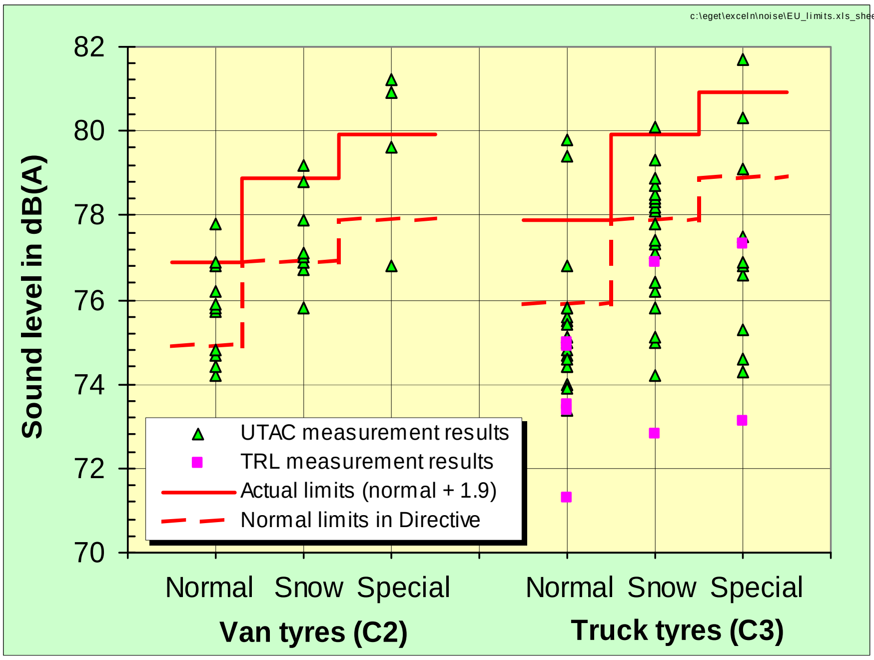
The broken (red) line in Fig. 12 shows the nominal limit values. However, the measuring method requires that measured values be truncated, i.e. decimals shall be deleted. Furthermore, measured values shall be reduced by 1 dB. The latter intends to give the industry an allowance for possible measuring errors. In practice this means that a measured level of 75.9 will become 74 dB when a comparison with limits is to be made, i.e. the actual limit in relation to what one measures is 1.9 dB higher than the nominal limit. The actual limits are indicated in Fig. 12 as a solid (red) line.

Also shown in Fig. 12 are measured values, one point per tyre, on which the limits are based. Most of these data were measured in 1992-93 and are also part of Fig. 8. Note that several of the car tyres that exceed the limits in the figure in fact are reinforced or special tyres that are allowed an extra 1 or 2 dB. Thus it can be seen that only very few of the tyres of one decade ago will exceed the limits; about 9 % of the car tyres, 17 % of the van tyres and 7 % of the truck tyres.

More recent measurements [13] indicated that the limits were not exceeded by any tyre of 48 car tyres tested, using two of the most commonly used tyre widths. It is possible that the reason for this result is that the vehicle noise limits introduced from 1996 caused an indirect tyre noise reduction, see the last part of this Chapter.

However, the European Tyre and Rim Technical Organisation (ETRTO) considered the limits as being 2 dB too *strict*, see the introductory "Motivation" in [24].





<u>Figure 12:</u>
Noise emission limits that new tyres will have to meet according to an amended tyre Directive 92/23/EC. Also tyre noise levels measured by three organizations are indicated (one tyre per point); see Chapter 9 above. Car tyres in the upper diagram, van and truck tyres in the diagram below.

Apart from the limit values, it is important to consider which tyres that are subject to the directive and when the limits will be in force.

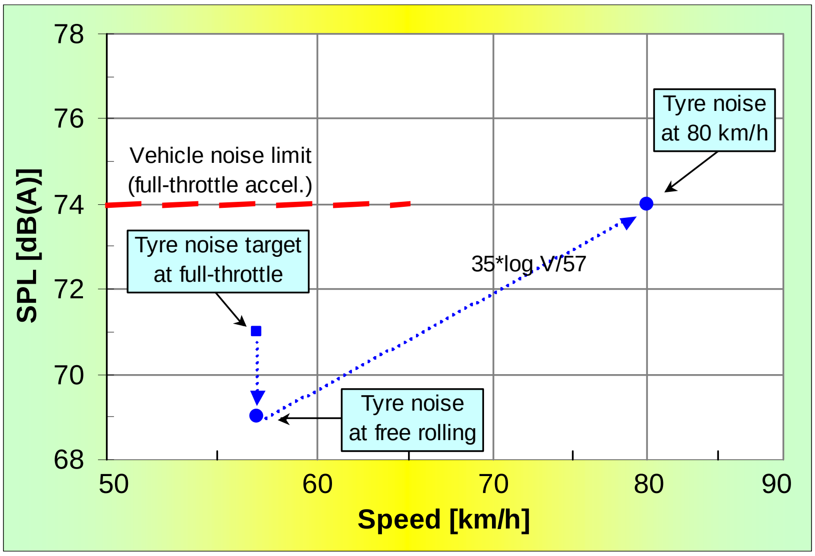
First, the time of enforcement: At the time of writing, confirmation decisions are still needed by the Council and the Parliament, after which the amended directive will be published. This author estimates this to happen earliest by 1 July 2001. Then the limits shall come into force within 18-30 months after publication, depending on what type of tyre approval that is sought. Thus, the limits will probably be enforced from the beginning of 2003. A lowering of the limits of 1 dB for car tyres from 2007-2009 will be considered later (not yet decided).

All tyres that need type approval are subject to these limits, i.e. essentially all tyres for road vehicles, except retreaded tyres. The latter constitute around 25 % of the car tyre market and 50 % of the truck tyre market (in Sweden). Therefore, 25-50 % of the tyres on vehicles in Europe will not be subject to the limits. Furthermore, it takes at least 10 years before all vehicles are equipped with new tyres that have been tested against the noise limits.

This author's estimation is that, if the limits were sufficiently low, they would start to affect road traffic noise around the year 2005 and then gradually have an increasing effect until reaching its full impact around 2010. However, first one must consider that 25-50 % of the tyres (the retreads) will not at all be covered by the directive. It means that, overall, roughly 50 % of a noise reduction (based on L_{eq}) achieved for the average *new* tyres can be obtained. But, the main problem is that only very few new tyres will be replaced with improved types: the estimations above range from 0 to around 10 % of the tyres. It can be shown that if the noisiest 5 % of the noise level distribution of Fig. 12 (car tyres) were replaced with 3 dB less noisy tyres, the L_{eq} would be reduced by 0.2 dB. Consequently, around year 2010 we might enjoy approximately 0.1 dB of reduced traffic noise L_{eq}, i.e. the tyre/road noise part of it. This is of course totally negligible. Even a sharpening of the limits by 1 dB from 2007-2009 that will be considered will be inefficient.

Tyre manufacturers must not only make sure that their tyres meet the limits outlined above, they also have to meet the requirements of the vehicle industry. Of course, vehicle manufacturers look (listen) very carefully at the tyre/road noise inside their vehicles, but they also need tyres that are sufficiently quiet at the exterior during vehicle noise testing according to the ISO 362 method and its corresponding EU Directive and ECE Regulation. This feature is addressed in Fig. 13 (only for car tyres).

Figure 13:
Attempt to illustrate how the current vehicle noise limit (74 dB(A) for cars) result in target requirements on tyre/road noise from tyres subject to considerable torque. This tyre noise target with torque can be translated to a target at free-rolling and further translated to a corresponding noise level for free-rolling at 80 km/h.



Since 1996 new cars have to meet a nominal noise emission limit of 74 dB(A), tested at full-throttle acceleration on 2nd and 3rd gears past two microphones from a start speed of 50 km/h up to around 65 km/h. This is illustrated as the broken line at 74 dB(A) in the figure. A vehicle manufacturer would then probably require that tyre/road noise is at most 71 dB(A), since this gives the vehicle manufacturer the possibility to have 71 dB(A) from the power unit of his vehicle. If he would accept 72 dB(A) of tyre/road noise, his power unit noise would have to be lower than 70 dB(A) and this would not be very easy. Therefore, we can assume that the target tyre/road noise would be maximum 71 dB(A), at full-throttle acceleration. The noise increase due to torque at such accelerations range from 0 to 6 dB, depending on tyre [17], so if choosing 2 dB, this is a conservative value. Tyres meeting the 71 dB(A) target for full-throttle would then emit approximately 69 dB(A) at free-rolling; probably lower. The speed would be around 57 km/h, since this is approximately an average speed of accelerating vehicles (average for the 2nd and 3rd gears) when the maximum noise level is read. Assuming a speed coefficient *B* of 35 (see Chapter 5), 69 dB at 57 km/h corresponds to 74 dB at 80 km/h, the latter of which is the reference speed for the tyre noise limits of 92/23/EC.

This means that tyre manufacturers supplying tyres to vehicle manufacturers are likely to be forced (indirectly) by vehicle manufacturers to supply tyres that emit maximum 74 dB(A) during a test according to the 92/23/EC. This is lower than the 92/23/EC tyre noise limits for all tyres except the very smallest ones. It follows that the requirements of 92/23/EC coming into force in a few years are already much less stringent than the indirect limits following from the current vehicle noise limits and that came into force almost 10 years earlier.

15. Conclusions

This paper has attempted to present a review of some of the most important topics of current interest in the subject of tyre/road noise, by listing and analyzing some "myths" that seem to have been rather commonly accepted among part of either the scientific or the administrative-/authoritative community. The conclusions are as follows.

Tyre/road noise, as we know it today, is something that has been of great importance at least since the 1960's. However, before the days of the pneumatic tyre, tyre/road noise was of great concern in cities for centuries. Already in the Roman Empire, this was a problem.

Tyre/road noise was considered a typical high-speed, extra-urban problem in the previous decades. However, current knowledge suggests that this type of noise gives a higher contribution to overall vehicle noise than all other types of vehicle noise together at all constant-speed driving of (new) light vehicles except on the first gear. For heavy vehicles, this is the case for speeds above about 40 km/h. Acceleration (or engine braking) will change this picture a little, limiting the tyre/road noise domination to somewhat higher speeds and gears. However, tyre/road noise is nowadays no doubt a very serious urban problem.

Looking in the rear mirror, the changes in vehicle noise emission during the latest three decades *in actual traffic* has not been impressive. One would like to think that all the work made by acoustic engineers has been very successful. It is true that at low speeds, power unit noise has been reduced a lot – for heavy vehicles at least – but at high speeds the reduction is almost nil. It means that tyre/road noise has not been reduced to any significant degree.

Speed influence on noise, which is the largest of any influence, has been looked at as something very "simple" and not very interesting to explore, but the paper attempts to show that there are still some interesting features that seem to have been neglected; like the relation between the "speed coefficients" *A* and *B*.

Road surfaces are generally regarded as the second largest influence on tyre/road noise. It is shown that this is both right and not so right. Taking all road surface types and conditions into consideration, the spread between road surfaces is extremely large. However, many of the surfaces are very special and not generally useful. Some others have their extreme effect only when new. It is also rather commonly thought that a rougher texture automatically creates higher noise levels of rolling tyres. The latter is a pure myth and can be rejected.

Quite a few organizations have concluded that the differences in tyre/road noise emission between different tyres, in contrast to that between different roads, is small. The paper shows that when considering a wide range of tyres, and in different condition (just as when comparing road surfaces), the noise level range is large; comparable to that of road surfaces. It is also shown that the myth that winter tyres are noisier than summer tyres is false.

The width influence on tyre/road noise emission is large; albeit not as large as has been thought at some times. It appears that the width influence that one finds when studying car tyres only, can be extended to tyres of very different sizes, like bicycle and heavy truck tyres (the extended relation fits well an extrapolation of only car tyre width influence). Perhaps surprising to some, it appears the noise increase with width is less pronounced in the higher width range. For example, it means that one can find heavy trucks that emit lower tyre/road noise than some cars. It is not so much the size that counts; it is the number (of tyres)....

Due to the success of tyre manufacturers to randomize their tread patterns, it is often expected that tyre/road noise be of a broadband character. This is true in the meaning that one would hardly hear tones in the spectrum any longer. However, it seems that the sound energy has become very much concentrated in the octave of 1 kHz; typically 70 % of the sound energy is emitted within this octave. This does not give a tonal impression, but it means a coloring of the sound that may be a problem necessary to address. At least, in order to reduce tyre/road noise levels, one must concentrate on this octave, and look at ways to spectrally separate the various generation mechanisms that contribute to the spectral concentration.

It has been assumed by many that when lowering tyre/road noise, by some automatic mechanism one will also decrease safety. In the paper, some recent studies rejecting such a simplistic view are presented. It appears that no compromise between low noise and high wet friction has been detected. It also appears that there is no conflict between low noise and low rolling resistance; the weak relations obtained are in fact favourable to both.

The Inter-Noise 2001 theme is "Costs & benefits of noise control". The paper addresses this topic by attempting to estimate a monetary evaluation of tyre/road noise (effect on residents) per vehicle-km. It is estimated that a cost increase in tyre purchase, due to noise reduction, of up to 50 % can be economically favourable for society, provided one can achieve a 4 dB noise reduction. This is only a first attempt that should be regarded mainly as a calculation exercise and it is possible that even much higher cost increases may be favourable. Not only is it likely that noise reductions by tyre selections and -measures are cost-effective; it is also shown that shifting from a conventional to a low noise road surface may be economically very favourable. Furthermore, it is shown that a low noise road surface may be competitive and even superior to building noise barriers in certain noise exposure situations.

Finally, the effect of the recently decided tyre noise emission limits that will be included in the 92/23/EC Directive of the European Union is explored. The aim of this is clearly to reduce road traffic noise in the future. However, it is shown that the selected limits, after "discounts", are not sufficiently stringent to have any significant effect on traffic noise. Only very few tyres will be affected/eliminated by the limits; a recent study even concluded that none of 48 tyre types tested violated the limits. In the very best case, the limits will affect road traffic noise (L_{eq}) by a few tenths of a decibel, which will be totally negligible.

It is also shown that vehicle noise emission limits should have (indirectly) limited tyre/-road noise to levels that are for all but the very smallest tyres well below the new EU tyre noise limits. Thus, we have already many years lived with tougher limits than the new ones.

Therefore, the final conclusion of this paper is very pessimistic: We cannot expect any road traffic noise reduction in the coming 10 years due to improved tyres, unless the tyre and/or vehicle industry makes something beyond the requirements by the authorities. This is a glaring contrast to the suggestion in the paper that the benefits to society of improved tyres would motivate even very high tyre cost increases.

Reduction of tyre/road noise appears to be one of the most interesting and important environmental challenges of the coming decades.

16. Acknowledgements

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