Sound basis...

Reducing noise, vibration and harshness is a never-ending quest

ONE of the major challenges a modern automotive engineer faces is the reduction of noise, vibration and harshness (NVH), because it has become one of the yardsticks used by journalists and buyers to evaluate new cars. It is a never-ending quest. No sooner have they conquered the loudest noise, than another loudest becomes apparent...

In addition, humans seldom agree on what noise disturbs. So, for example, the typical diesel sound that might annoy some people can be music to others' ears. The silence of a luxury model may appeal to older people, but more exhaust noise is needed to sell a sportscar. In this way, the general noise level in a car contributes greatly to our feelings about the car, and is often among the reasons why some models appeal to more people than others.

Noise, vibration and harshness are closely linked, because noise is created by vibration, and even harshness is just a vibration whose noise we cannot hear. A distinction should also be made between sound and noise. Sound is a general term, but noise usually refers to an unwanted sound.

Noise is created by vibration

SOUND THEORY

PROPAGATION OF SOUND

Sound is transmitted as an energy wave travelling through gases, solids or liquids. The medium through which it travels does not move any appreciable distance, but the atoms vibrate back-and-forth about their rest position. This explains why sound cannot be transmitted in a vacuum.

The speed at which sound travels depends on the transmitting medium and, in the case of a gas, this changes noticeably with temperature and pressure. For example, at zero degrees Celsius and 101,325 kPa (mean sea level), sound travels at 1 235 km/h, but at 627 degrees Celsius it has speeded up to 2 124 km/h. Sound also speeds up when it gets transmitted through material that is less compressible than a gas, so the speed of sound in fresh water is 5 332 km/h. In concrete it travels at 11 160 km/h, and in steel it travels at 21 960 km/h.

AUDIBILITY

The loudness of the sound we hear depends on the frequency of the vibration. This is the number of wave peaks that pass any point in one second, measured in Hertz (Hz). The frequencies audible to a typical human vary from 20 to 20 000 Hz.

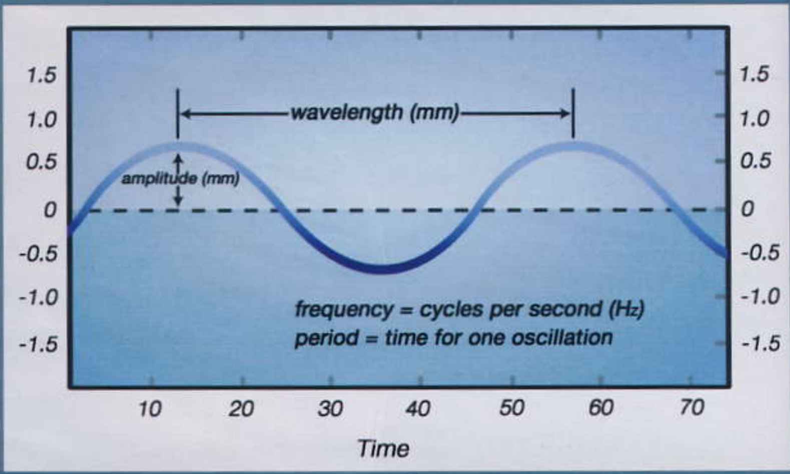
PRODUCING SOUND

The sound emanating from any mechanism can be classified as either directly or indirectly produced.

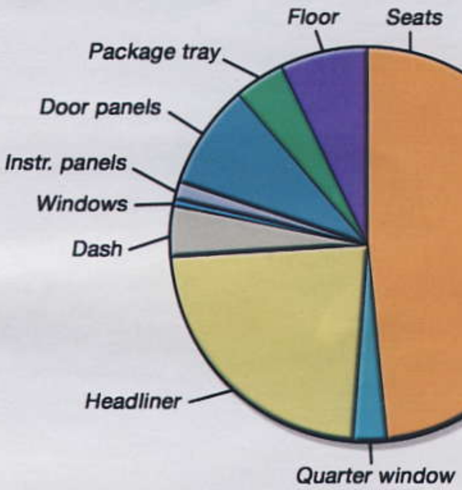
1. Direct generation occurs when sound is produced by a process such as combustion, or transfer of materials. Examples of such sound production include loudspeakers, exhaust tailpipes, engine combustion, fluid flow through pipes, fans, and jet engine noise. The level of sound produced in this way can be lowered by reducing the strength of the process or the size of the source. For example, engine noise can be reduced by slowing down the engine, or by reducing the displacement volume.
2. Indirect sound is generated when a fluctuating force produces a response in a nearby structure. Automotive examples include a steel sump or bell-housing that is excited by engine vibration, and any loose or large-area panel on a car. This type of noise can be reduced by lowering the amplitude or frequency of the force, or tuning a number of vibrating forces so that they do not resonate (interact positively). Failing that, the response can be altered so that its strength is reduced. For example, a vibrating panel can be made thicker, or given strengthening ribs. Many modern four-cylinder engines have balance shafts to reduce the amplitude, and the cars are fitted with a fifth or sixth gear to reduce the frequency of the engine's vibration.

MEASURING SOUND

The disturbance in the air that we call sound is, in fact, fluctuations in pressure, density and temperature. Since it is not easy to accurately measure minute variations in density or temperature, it is usual to measure sound



Above, left: two shafts, carrying suitable protrusions, rotate at twice engine speed parallel to the crankshaft, to balance the secondary vibrations in this four-cylinder diesel. Below, left: the percentage of sound absorbed by the various components of the interior trim is show here graphically. Above: the sketch illustrates wave terminology.



levels by using a microphone that is sensitive to fluctuating pressure.

Sound pressure levels (and sound power levels) are usually measured in decibels. The mathematical definition of a decibel is too esoteric to reproduce here, but the scale is chosen so that everyday sounds fall in the 0 to 160 dB range. Heavy machine noise is usually above 70 dB, and the human voice produces sound in the range from 30 to 70 dB.

The decibel scale is based on the logarithms to the base 10 of the numbers, instead of the numbers themselves, because this closely approaches the way the human ear experiences sound. This implies that two decibel numbers are added or subtracted by performing the same operations on their logarithms. The result is that when two identical sound readings are added, the result is a sum that is only three dB greater than the original readings. It also means that when a sound level one tenth of another is added to the larger unit, the answer is only very slightly bigger than the size of the larger unit. This means, for example, that a number of noise sources acting together will only increase the noise level by a small percentage of the total that would be obtained from adding the readings together using normal arithmetic.

All this weird arithmetic makes decibel reading differences difficult to interpret, but the following guidelines, valid for same-source readings, will help:

1 A one decibel change in the level is barely perceptible.
2 A three decibel change in the level is clearly perceptible.
3 A ten decibel increase in the level appears as a doubling of the loudness.
4 A ten decibel decrease in the level appears as a halving of the loudness.

Most sound level meters can be adjusted for at least three sensitivity levels, because without such an adjustment the readings may be distorted to some extent at the upper and lower sound ranges. These levels are labelled A, B and C, and for outdoor and vehicle interior measurements, the A-weighing is commonly used. This reduces the sensitivity of the instrument for both low and very high frequency sounds.

RADIATION OF SOUND

The appreciation of sound level readings is further hampered by effects arising from the surroundings. In an enclosed space, the sound is reflected from all the surfaces so, for example, when measuring the sound level in a car, the reading is affected by the interior shape as well as the materials employed. This means that the same noise sources will register differently in different car interiors, but the sound reaching our ears will be affected in the same way, so the readings are still valid for comparative purposes.

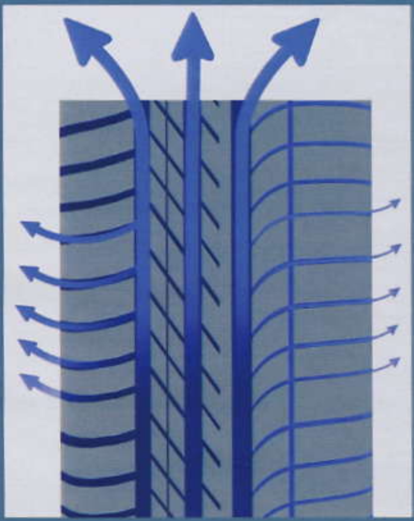
When trying to get a single-source reading in the open, the results will be affected by a number of factors. These are the actual sound power level, the direction of the source with respect to the instrument, the distance between the source and the receiver, and the attenuation (combined effect of scattering and absorption) due to the surrounding shrubs and natural features.

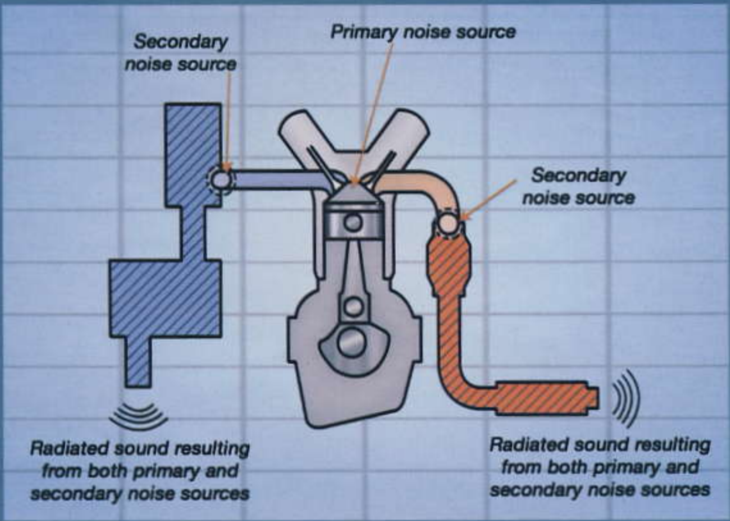
CAR SOUNDS

In the early days of motoring, the most prominent sources of noise were the open exhaust systems, but as soon as rudimentary silencers became fashionable, the gearbox took over this role. All gears were straight-cut, and whined whenever any load was applied. Some cars, such as the Bullnose Morris from the '20s, were so noisy in anything except top gear that uphill motoring had to be conducted in silence!

Then manufacturers started fitting helical gears, except for first and reverse, thus

Balance shafts reduce the vibrations





Far left: the various escape routes that air and water have to take when a tyre is compressed on the road surface play a role in determining the particular design's noise level. Left: this sketch illustrates the various types of noise sources.

making gearboxes a lot quieter. Some idea of this noise can be gathered by reversing fast in one of the less expensive cars, like a Toyota Yaris. Such models still have straight-cut reverse gears, resulting in a distinctive whine. This noise is not always unpleasant – most pre-war Bugattis utilise a straight-cut gear train to drive the camshafts, and the resulting noise, likened to tearing a sheet of calico, can be very addictive.

Up until about 1960, exhaust systems were the noisiest parts on most vehicles, as measured during full-throttle drive-by noise evaluation. Then customers as well as regulatory bodies started demanding quieter cars, and the industry responded. This movement was accelerated by the move towards front-wheel drive, because removing the rear axle increased the space available for a silencer, allowing larger units to be fitted.

The intake system then became the noisiest drive-by source, and efforts to quieten this down were again aided by a new technical development – port fuel injection. This enabled the use of plastic intake manifolds that are less prone to reverberation.

Tyre noise then took over as the main source, but as tyres become quieter we've now reached the situation where exhaust, intake and tyre noise are more or less on a par when it comes to measuring full-throttle drive-by noise in second or third gear.

Of course, the driver and passengers have a different perspective, because they are cocooned in an enclosed, sound-deadened space.

INTAKE AND EXHAUST SYSTEM NOISE

It's obvious that noise in the manifolds is caused by the air flow, but a number of components can be identified. The primary source is the fluctuating flow through the valves, which appears as a noise mainly at the intake orifice or the exhaust tailpipe. The friction caused by the steady component of the flow is also noisy, but usually to a lesser extent. Both noise components can be attenuated by large, well-designed intake and exhaust silencers. In addition, these noise sources very often cause the air cleaner and silencer to resonate, creating not only additional noise, but sometimes leading to failure of these components. It's interesting to note that the addition of a turbo- or supercharger reduces intake noise, presumably because the charger housing space acts as a silencer.

Turbocharging reduces intake noise

MECHANICAL ENGINE NOISE

Once the intake and exhaust sounds have been reduced, various mechanical sounds present themselves. Valve tappets used to be noisy, but these days most engines have hydraulic valve clearance adjustment. This not only results in a noise reduction, but also eliminates the need for regular adjustment. Some engines were prone to piston slap. These days this is masked rather than cured by enclosing the top part of the engine in sound-deadening material. This is so effective that most modern pistons no longer have skirts, thus increasing the noise caused by the piston's natural tilting tendency as it moves down the bore. The advantage of a lighter piston is that it reduces the inertial load on the bearings. Turbo- and supercharger noise is mostly masked by engine covers, but on some engines a slight whine can be heard.

TYRE AND ROAD NOISE

If you live close to a freeway, it is likely that one of the major components of the steady drone you'll hear is tyre and road noise. The interaction between tyres and the road often creates more noise in an expensive car than in a cheaper model, leading to disappointment. This is usually a false judgement because what really happens is that the other noises are so well masked or damped in an upmarket model that tyre noise is now the most prominent of the remaining noise. This can easily be checked by coasting an expensive vehicle and a budget model in neutral. The results will show that the cheaper car actually has more road noise.

Engineers don't always agree on what actually generates the most noise in a tyre, but two sources have been identified:

1. Air-pumping noise created when air is displaced in and out of the tread and road cavities during contact with the road. Tyre tread design plays an important role, but this is a very complicated subject. One example of the on-going research is the finding that deep, cross-grooved treads tend to produce more noise than longitudinal grooves – but the former help traction on loose surfaces.
2. Noise created by tyre vibrations resulting from contact with the road as well as tyre irregularities. Experiments with smooth tyres compared with treaded tyres have shown that this kind of noise exists as an additional source.

Both these noise sources are affected by tyre construction, tread pattern, the road surface, and the vehicle speed.

Noise reduction research is a vast subject that quickly gets very technical, but in a future issue we plan to follow up with an overview of the latest and possible future noise reduction techniques. car