Chapter 8.

Keeping Things Quiet.

Silencing – the Problem.

Whilst there is an element of truth in the general belief that performance and silence are mutually exclusive the main problem is one of perception. Most enthusiasts expect a high performance car to sound like one!

Although the dynamic effectiveness of pulse activity in the outer reaches of an exhaust system can be threatened by the need for silencing there is no reason why the stages adjacent to the engine cannot remain very effective, as is the case with induction systems.

Any significant resistance to flow will result in back pressure, which will reduce engine performance but this is something that becomes more significant as engine speeds and flow rates increase. Because of this relationship with speed, exhaust restrictive back pressure has a greater adverse effect on power output than it does on mid-range torque.

It is a certainty that if the current EU noise limit of 74dB(A) for production cars were imposed on F1 racing cars the lap times would hardly change, but the crowds certainly would – for the worse – because the glorious howl of a racing engine at full power is very much part of the spectacle, although possibly some moderation to a less extreme level could be beneficial.

Road cars are a different issue but the problem for legislators is that it is very difficult to define a noise test cycle that is representative of real world driving, taking into account all engine noise, tyre noise and wind noise. It would also be rather pointless if it did not also include 'in-car-entertainment systems' which some might consider to be a very considerable source of annoyance. Some noises and tones can be more pleasing than others, although any consensus on which are best and which are worst is completely impossible.

Then there is the problem of devising a simple roadside test that is viable for enforcement purposes or that can be incorporated into a procedure like the MOT. Noise measurement is notoriously dependent on background conditions and the exact positioning of the sensing device relative to the source. A scientist would be scornful of the use of anything less than an anechoic chamber but in the real world something more rough and ready will have to suffice.

It will be tough to come up with anything better than a subjective opinion, but of course it can only be a matter of time before some committee of bureaucrats devises some sort of 'solution' to impose on us all.

The Source of Exhaust Noise.

We have seen how pressure changes take place in the exhaust ports of an engine to produce waveforms that can be synchronized for most effectiveness with respect to performance. In reality these apparently simple waveforms are very complex with all sorts of minor peaks and troughs superimposed on the basic shape. These indicate lots of changes of pressure at compound frequencies which have no real bearing on the dynamics of charging and discharging the cylinder but do contribute to what we perceive as exhaust noise.

It was explained how the early part of the discharge as the exhaust valve starts to open takes place at sonic velocity but sonic velocity falls as the temperature of the gases falls. The cylinder pressure will also be falling which causes a reduction in the mass flow for a given passage area but of course the area is increasing as the valve opens. Clearly, despite the apparent stability of sonically choked flow, the conditions for gas flow change rapidly which is just one factor contributing to the complexities of the pressure changes in the system. In fact the conditions for exhaust flow change continually throughout the process from start to finish so the sounds created range from large peaks related to the engine speed to higher frequency notes related to the dynamic and acoustic properties of the entire system.

All sound waves are pressure waves so they all respond to features like joints and collectors in essentially a similar fashion. An engine equipped with a well designed highly resonant performance exhaust system is bound to generate a lot of noise, but it is possible to reduce the level of noise emitted to atmosphere without too much loss of dynamic efficiency.

It is also useful to be aware that flow through the system can actually induce noise from turbulent wakes at corners and edges. This is known as ‘self noise’ and whilst it is generally low magnitude it obviously works against the purpose of the system to reduce emitted noise. The flow conditions therefore need some consideration in this respect in addition to the need not to impede flow.

Sound Perceptions.

Most people are aware that what we perceive as sound is energy in the form of pressure waves. The human ear can detect sound over a tremendous range of amplitudes from the ticking of a watch to a military jet engine at full thrust. The decibel (dB) scale was devised so that the volume of any sound could be defined in a numerical manner without involving vast numbers of increments. 0 dB represents the lower threshold of hearing and a sound 10 times louder is 10 dB. 100 times louder is 20 dB, 1000 times louder is 30 dB, and so on. 130 dB is considered to be the threshold of pain. The method of arranging multiples of 10 in this way is called logarithmic.

Because the human ear has more sensitivity to sound between the frequencies of 1000 Hz and 5000Hz a correction is usually applied to the dB scale to take our perception into account. The corrected scale is expressed as dB(A).

The brain’s interpretation of sound can seem puzzling. For instance if an engine was measured as producing 60 dB(A) and a second identical engine were started up alongside, the combined reading would be 63 dB(A). This may seem absurd but to our ears the sound level would be hardly any different. In the same way we don’t notice a great deal of difference between the noise from a jet fighter at take off and a bomber powered by four of the same engines. The difference between the two would only be 6 dB(A) because of the logarithmic connection. When loudness as we perceive it is doubled it approximates to an increase of 10 dB(A).

Frequency is another important dimension of sound. Most sounds are composed of a broad spectrum of frequencies even though they might start out as a single event. This is because of the various reflections, eddies and other inconsistencies that become superimposed on the original sound. A clap of thunder is a good example; when very close by it takes the form of a very sharp crack, perhaps even a fizz, yet a person a couple of miles or so away will hear crashing and rumbling that may linger for several seconds.

Methods of Attenuating Exhaust Noise.

Most modern cars have catalysts (catalytic converters) in the exhaust system to control emissions. Because of the fine matrix construction of these devices they do make some contribution to the reduction of exhaust noise in the first stages of the system.

The mechanism for this is simply friction scrubbing loss as a result of viscous drag inside the numerous small channels which can be seen in the photograph (Fig. 8.1). Viscous drag produces a pressure difference across the matrix that is proportional to flow rate so the effect becomes more significant as engine speeds rise, as does the restriction on flow and consequent back pressure.

As a means of silencing this is not very efficient but it does allow some latitude in the design of the remainder of the system which may be less restrictive than might otherwise be the case. For the same tailpipe noise level a system containing one or more catalysts will produce slightly more back pressure at the exhaust manifold although for reasons explained above engine torque may not suffer anywhere near as much as top end power. Such losses are obviously related to the cell density of the matrix and may not be very significant in lower density types.

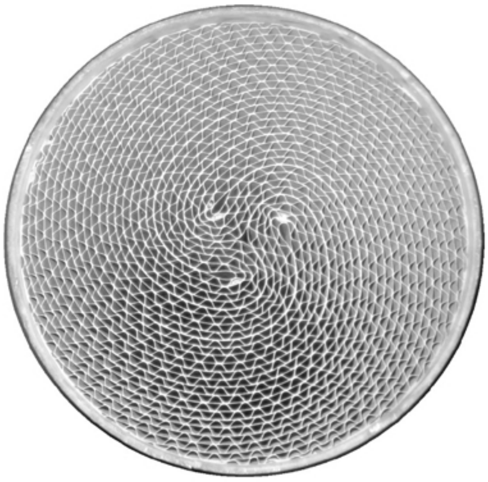

Fig. 8.1 End view of catalyst matrix.

Silencers (Mufflers).

There are several techniques that can be used to reduce the exhaust noise produced by an engine and often a combination of methods will be incorporated into one silencer box.

Whatever the type of silencer it must have a rigid outer skin that will resist flexure with pressure changes. This is usually achieved by having a circular or oval cross section and sturdy end plates with the edges pressed over to form flanges. Any flat or nearly flat surface that rings when tapped will almost certainly resonate at some frequencies, usually adding an unpleasant timbre to the exhaust note.

The Quarter Wavelength Rule.

If a sound wave enters a chamber and travels a distance equal to one quarter of its wavelength and is then reflected back to the point of entry it will arrive there half a wavelength out of phase with another wave of the same frequency following behind. Consequently the positive peak of one wave will coincide with the negative peak of the other and if they then travel together in the same direction they will counter each other through destructive interference. This is also true if the length of the chamber is an odd multiple of one quarter of the wavelength.

Of course, even multiples of a quarter wavelength are half wavelengths which means the reflected wave then arrives in phase with the next one so there is no attenuation.

It should also be remembered that the speed of sound changes significantly with temperature as does the wavelength at any given frequency so the required length for a quarter wave reflection in an exhaust system will increase as engine load (and exhaust gas temperature) increases.

1. The Reflective Silencer.

The simplest method of silencing is by reflecting sound waves either back to the engine or in such a way that several waves can counteract each other. This is what happens in an expansion box, which is surprisingly effective and can be embellished in a number of ways (Fig. 8.2).

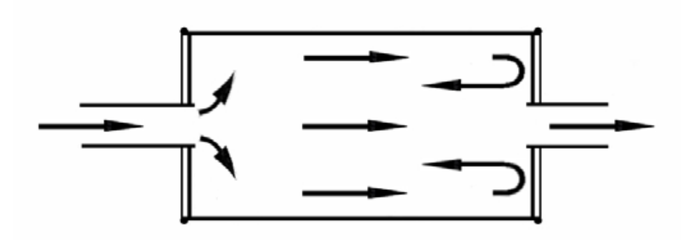

Fig. 8.2 A simple expansion box.

A sound wave expanding into a chamber creates an inverted reflection back towards the engine just as a pressure pulse does. The remaining sound energy continues through the chamber until it reflects back from the far end without inversion. It then rebounds back to the incoming end where again it is reflected back. If, at this moment, another sound wave is entering the chamber and it happens to be in opposite phase they will interfere destructively leaving a wave of much lower magnitude. If the length of the chamber is one quarter of the sound wavelength (or an odd multiple thereof) this will happen most effectively but clearly the process can never be totally effective or there would be nothing left to provide the next reflected wave needed to continue the action.

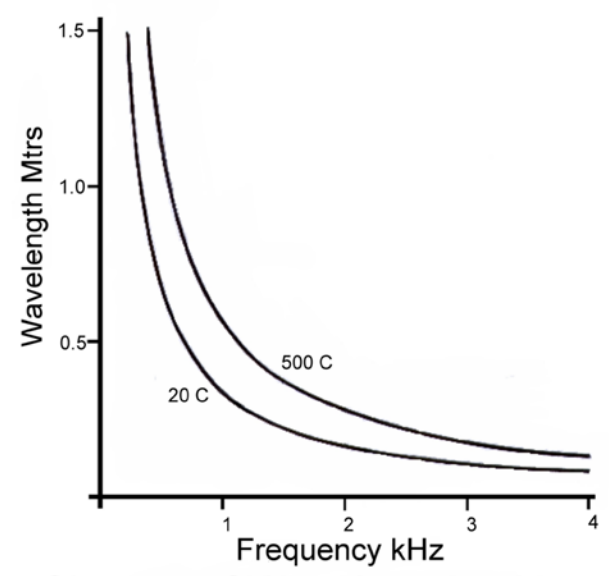

Fig. 8.3 Wavelength change with frequency and temperature.

At some different frequency the incoming sound could arrive to be in phase with the reflected wave in which case they will interfere constructively and the resulting wave will be increased in magnitude. Wave energy will continue reflecting internally with the result that there is no significant difference between the magnitude of sound entering and that passing through to the outlet.

To complicate things further the exhaust gas temperature will make a profound difference to the frequencies that will be attenuated in a given chamber. The diagram (Fig. 8.3) shows how wavelength varies with frequency and also that rising temperature will increase the wavelength at any given frequency. A reflective silencer will therefore be effective over different frequencies when an engine is idling than it will at full throttle. This can explain puzzling anomalies like how an exhaust system can seem to be reasonably quiet whilst being driven under load yet unpleasantly loud when the engine is idling.

11 pages follow.