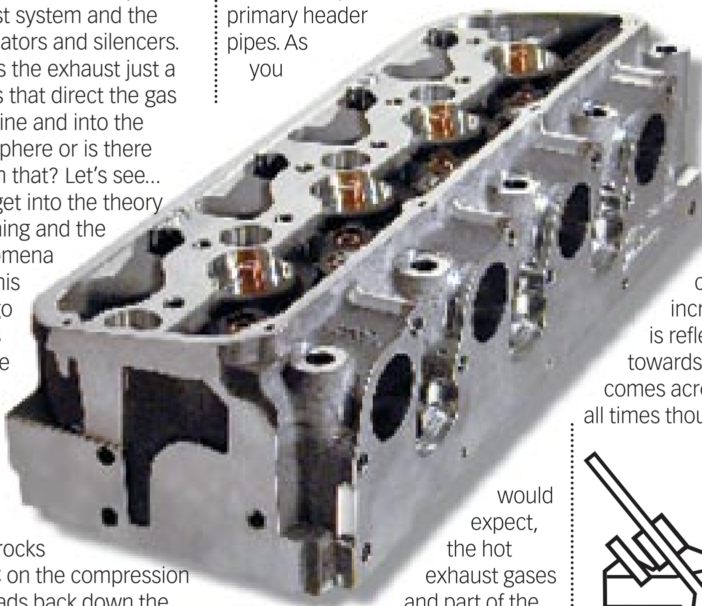
EVERYTH ING FLOWS

Stu's words of wisdom. This month: exhaust tuning, theory and practise.

LAST month we talked about the cylinder head: how best to get your fuel and air in and then back out of the head for both ultimate performance and best engine efficiency.

So it seems natural that this month we deal with what happens after the gas leaves the head via the exhaust ports. The majority of you will already know that it enters the exhaust manifold from here, and is then routed to atmosphere via the exhaust system and the exhaust resonators and silencers. So, is that it? Is the exhaust just a series of pipes that direct the gas out of the engine and into the waiting atmosphere or is there more to it than that? Let's see…

Before we get into the theory of exhaust tuning and the various phenomena surrounding this subject, let's go back to basics and look a little more closely at the life of an exhaust gas charge.



IN THE MIX

As the piston rocks over from TDC on the compression stroke and heads back down the bore on the power stroke, the mixture burn has already been initiated, and thus the rapidly-burning mixture releases masses of energy. This is then transferred to the crankshaft via positive pressure on the piston crown.

Once the burn is over and expansion ceases, we are left with a certain amount of red-hot waste gas and particle matter. This waste is commonly known and referred to as exhaust gas, and although nothing like the pressure it had during the power stroke, it is still at very high pressure.

Just before bottom dead centre, the exhaust valve opens and the gas naturally starts to exit the cylinder due to the pressure differential created, so it flows to the lower pressure exhaust port and out into the awaiting exhaust manifold headers, creating a high-pressure wave as it does so.

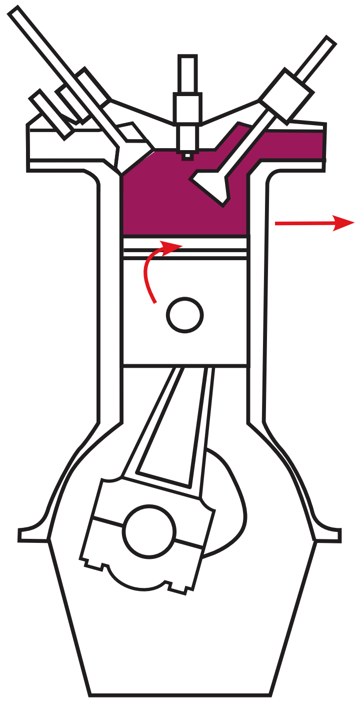
From the exhaust manifold primary header pipes it travels down to the point where all (or some) of the cylinders' primary headers converge with each other. This point of convergence is known as the collector. Once in the collector, the exhaust gases expand quickly as the pressure wave propagates into all of the available space and the other lower pressure primary header pipes. As you would expect, the hot exhaust gases and part of the pressure wave energy make their way out of the collector via its outlet and into the main exhaust system, heading for the tail pipe via any resonator boxes and ultimately escaping to atmosphere.

Based on the above visualization, it should be quite clear that two basic, yet very separate entities are at work in the exhaust system: exhaust gas particle speed and the resulting pressure waves.

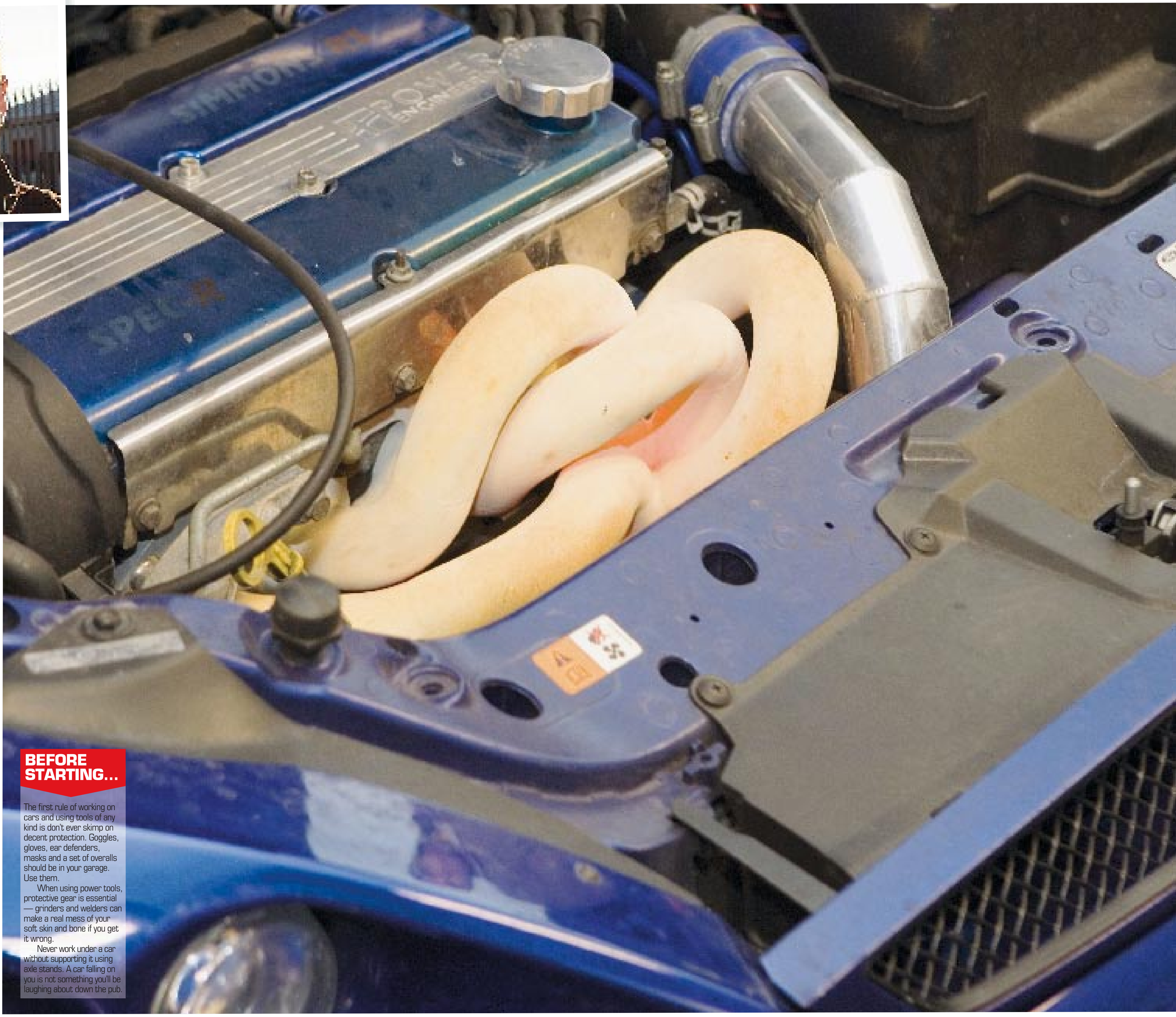
NEED FOR SPEED

The pressure differential between the cylinder and the atmosphere determines the exhaust gas particle speed — that much is relatively straightforward. As the gases travel down the pipe, rapidly expanding and cooling, the speed decreases. This is one of the reasons that people lag their exhausts manifolds and systems with heat-proof tape, or even ceramic coatings. To keep the heat in and the gas speed high.

Pressure waves on the other hand base their speed on the speed of sound. While the pressure wave's speed also decreases as it travels down the pipe due to gas cooling, the speed will increase again as the wave is reflected back up the pipe towards the cylinder when it comes across any restriction. At all times though, the speed of the



Above: exhaust gasses exit the cylinder at high pressure



BEFORE STARTING…

The first rule of working on cars and using tools of any kind is don't ever skimp on decent protection. Goggles, gloves, ear defenders, masks and a set of overalls should be in your garage. Use them.

When using power tools, protective gear is essential — grinders and welders can make a real mess of your soft skin and bone if you get it wrong.

Never work under a car without supporting it using axle stands. A car falling on you is not something you'll be laughing about down the pub.

Bends should be as smooth as possible

pressure wave is greater than the speed of the gas particles.

You need to understand that pressure waves behave very differently to gas particles when a junction is encountered in the exhaust pipe. When two or more pipes come together, as they would in any collector for example, the waves travel into all of the available pipes — backwards as well as forwards. Waves are also reflected back up the original pipe, but with a negative pressure. The strength of the wave reflection is based on the actual size of the collector, or at least the area size change when compared to the area of the pipe it travelled down there in.

RIDE THE WAVES

The basis of exhaust pressure wave tuning is essentially to harness these waves and make them do good things for us. The most common aim is to design and assemble the pipes so that the negative wave pulse reflection coincides with the period of intake and exhaust valve overlap.

This low pressure helps to pull in a fresh intake charge as the intake valve is opening and also helps to remove the residual exhaust gases before the exhaust valve closes.

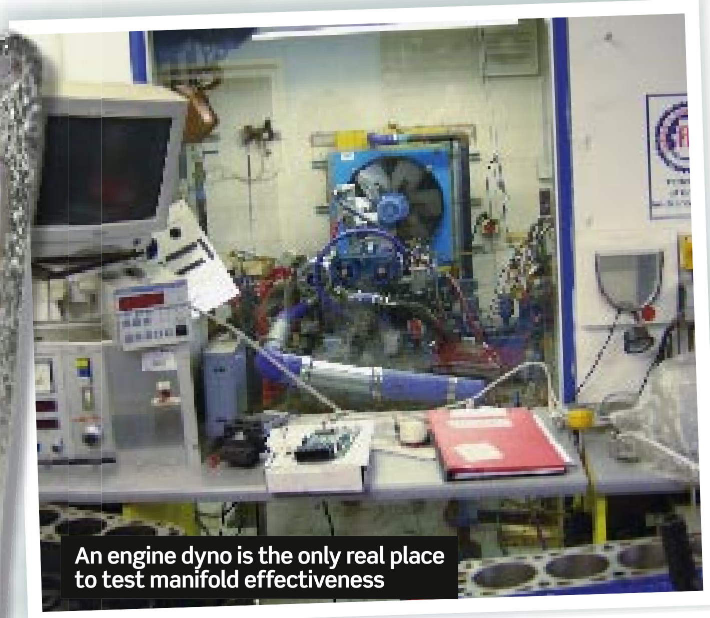
Typically this phenomenon and its effect is controlled by the length of the primary header pipe. Due to the extremely critical timing aspect of this tuning there will most probably be parts of the power curve where more harm than good is done.

This type of tuning can not be guessed and requires endless dyno hours to perfect. Haphazard guessing will normally end up with nothing more than a seriously compromised power curve.

Gas speed is not as simple to achieve and harness as you may at first think either. Having a gas speed that is too high suggests that the system may be too restrictive and this will hurt your top end power. Too little gas speed tends to make the power curve excessively peaky and thus hurt your low-end torque. Having nice big diameter tubes in your exhaust will allow the gases to expand, but this cools the gasses, slowing them down along with their pressure waves.

So there you have it folks, its not just a load of old bent tubes after all, well, it is, but the sizes and shapes they became bent into took many hours of dyno time for some very clever people to come up with, so don't go changing the shape of yours every time you come to a bump in the road will you?

This is a 4-2-1 manifold: four primaries lead into two secondaries which then flow to the single pipe



An engine dyno is the only real place to test manifold effectiveness

With exhaust tuning, bigger isn't always better

Exhaust manifold design is crucial to good power

EXHAUST COMPONENTS

What makes up your average system?

Exhaust system design is a balancing act between all of these complex events and their timing. Even with the best compromise of exhaust pipe diameter and length, the collector outlet sizing can and often will still make or break the best design. Let's take a look at an exhaust system broken down into its many different components.

HEADERS/PRIMARIES

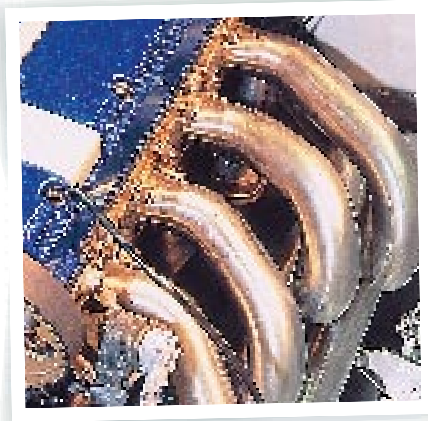
We must remember at all times that bigger is not always better with exhaust tuning. In fact, one of the greatest fears when designing an exhaust is that you will select a tube too big and lose some of the vitally important scavenging effect.

However, selecting a tube too small will add a flow restriction and rob us of bhp. It is still worth noting though that slightly too small is actually better overall than slightly too big due to the fact that slightly too small will lose a little top end power, but slightly too big will normally lose quite a lot of torque.

Header length has to my mind been over advertised and its importance blown out of all proportion for many years. As an example, how many times have you heard the term 'totally equal-length headers'? The first question you have to ask is, 'Did the engine actually need equal-length headers? If so, why did it not already have them?'

There are many engines out there that not only will not benefit from them, but may well positively suffer from the use of one. Many engine exhausts are tuned to offer maximum scavenging effect across a 3000-4000 rpm engine speed, so the fact that one exhaust header is tuned a few hundred rpm short of another is not of any great consequence and can in fact extend the torque range somewhat, even if it has dropped the peak efficiency down a few per cent.

Equal-length primaries don't suit all engines



Also worth considering is that the extra length from non-equal headers is normally used to best effect producing nice radiused curves, harnessing the available space in the engine bay.

All engine requirements differ and it has to be said that the common in-line, four-cylinder engine is proven to be most susceptible to header length and tends to like them as near to equal length as possible, but certainly not at the expense of nice radiused curves, free from nasty bends and harsh angles. So inspect those manifolds carefully before you hand over your hard earned. Equal lengths with nasty tight bends are not usually as good as unequal lengths but lovely smooth radiused bends.

Exhaust gasses expand quickly in the collector

COLLECTORS/SECONDARIES

Let's now take a closer look at the collector and secondary pipe configurations. It is not easy to discuss collectors/secondaries in general due to the various different configurations in existence, but the collector itself is the point where the primary headers join each other to flow into the secondary pipes.

In a 4-into-1 system we have a large all-in-one collector and a secondary pipe. In a 4-2-1 system we have a collector for each pair of headers, then a pair of secondary pipes flow the gas to one bigger collector that collects the gas from both secondaries

EXHAUST COMPONENTS

Correctly-designed silencers are vital for good flow

and directs it into our main exhaust system.

The first point to make about performance here is that the secondary pipe diameter is just as critical as the primary pipe. When choosing a diameter for the secondary pipe or the collector it is always good to start by multiplying the primary pipe diameter by 1.75. As for the secondary length, you are likely to find that experimenting here gives the most surprising changes on the dyno than any other part of the exhaust. Getting secondary lengths optimised will be worth power on almost any engine.

SILENCERS: BIGGEST POWER LOSS?

Inappropriate silencer selection will, in a very effective manner, destroy almost any advantages you gained by correct manifold, primary, collector and secondary pipe tuning.

The problem with silencers is that they are actually one of the most complex parts of an exhaust to get correct. The two factors we spoke about earlier need dealing with separately at the silencer if you are to make the exhaust work properly, and of course, legally.

The Pressure wave needs to be deadened by a suitable material to keep the system quiet for the road, yet the flow capacity of this sound absorbing material must still allow us to get the gas through with no major power robbing restrictions. Bear in mind we can't just make it huge and have lots of it, as the bigger the bore of the back box, the more sound we tend to generate.

The sound absorption is normally dealt with in one of two ways: The cheapest and most efficient way is to pack the rear box with a large amount of glass-fibre wadding and zig-zag our pipe through it, so by the time the exhaust gas and pressure wave exits the rear box, much of its energy is lost.

This system, whilst efficient at silencing, plays havoc with the flow and causes a power restriction. In its cheapest and most restrictive format is the reason that years ago one of the first mods we ever made to a car was a shiny and loud back box. And it was louder because...

The second most common type is the absorption type. This utilises a far better flowing design. Essentially the exhaust pipe runs directly through the back box, and in this pipe are drilled hundreds of uniform holes, almost like a sieve. Packed around this exhaust tube is a similar type of glass-fibre sound absorption material, but this time it is packed extremely densely around the exhaust tube and the pressure wave is attenuated as it flows through, what is essentially, a sound attenuation chamber. This type of system is harder to design and manufacture and normally offers less silencing ability but far more flow.

Performance cats usually flow better, but they're expensive

CATALYSTS

Finally, those law-abiding citizens amongst you with cars built from 1991 will know that their exhaust system utilises a catalytic converter. Sadly, if you have to have one of these then the possibility of you losing power via your exhaust system goes up dramatically, but all is not lost.

The first rule when dealing with catalysts is that we use the highest flowing components we can. A catalyst by its very nature is seriously restricting to both gasflow and pressure wave progress as all your exhaust gas must pass through a monolith (almost like a ceramic sponge) in order for it to do its job chemically and remove all the poisons from the gas.

Nowadays there does exist such a thing as a high-flow performance catalyst, available from all good exhaust suppliers. These catalysts have far coarser monoliths inside and flow gas far better than a production unit ever would. But they are currently still very expensive

NEXT MONTH

As part of our A-Z Of Tuning special, Stu gives the low-down on Ford's top engines

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