THE EXPERT
STEWART SANDERSON

Having worked as a tuner for 17 years, Stewart 'Stu' Sanderson is one of the most-respected names in the business.

A Level 5-trained fuel-injection technician, Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.

Eight years ago he joined forces with Kenny Walker and opened up Motorsport Developments near Blackpool (01253 508400, **www. remapping.co.uk**), specialising in engine management live remapping, as well as developing a range of Evolution chips which are now sold all over the world.

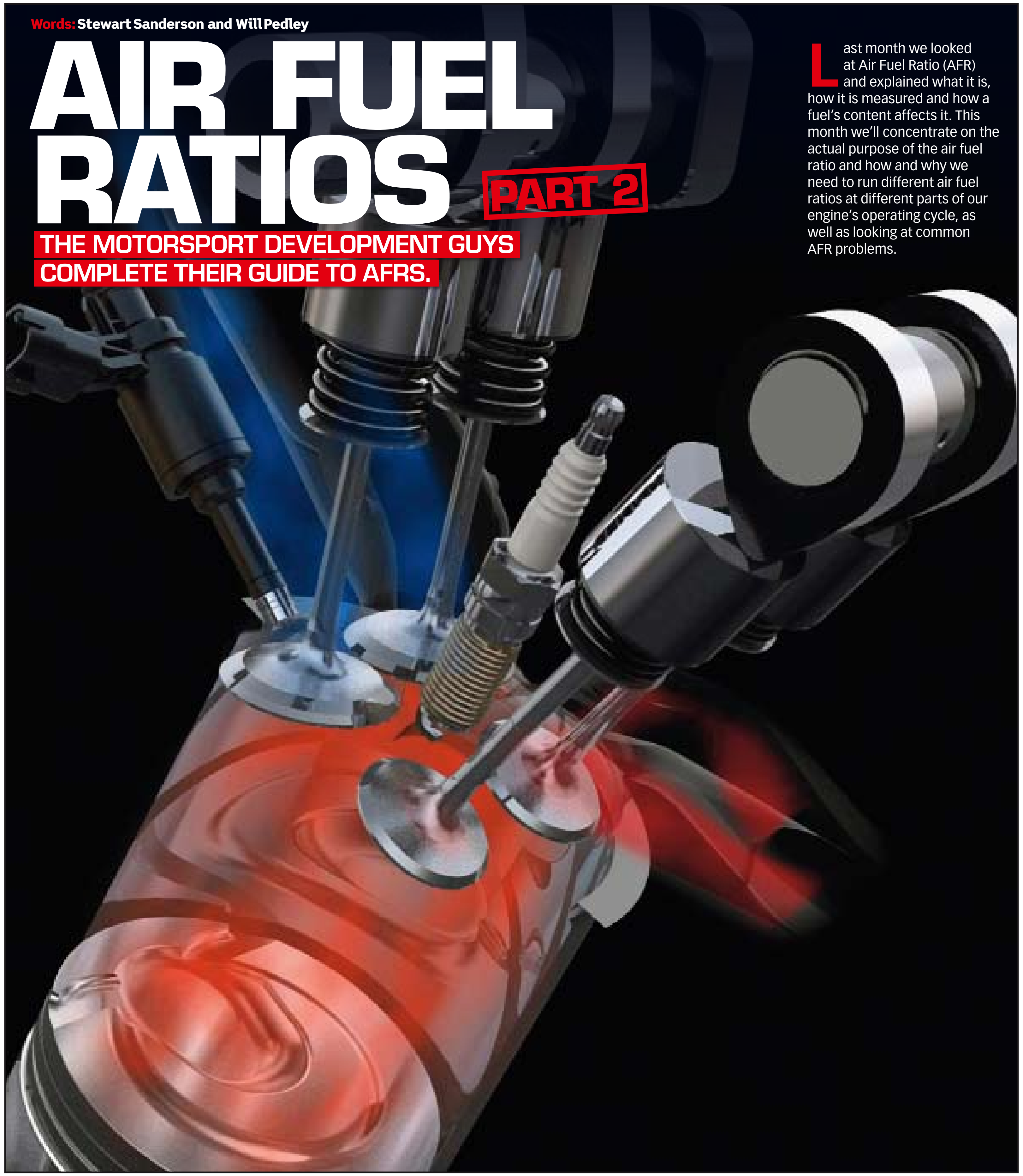
He is the creator and administrator of **www. passionford.com**, which he started in 2003. It has grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web.

Stu's enviable knowledge of the workings of modern-day Ford performance engines means that every month he's just the man to explain how and why things work, and importantly how they can be improved.

Words: Stewart Sanderson and Will Pedley

AIR FUEL RATIOS PART 2

THE MOTORSPORT DEVELOPMENT GUYS COMPLETE THEIR GUIDE TO AFRS.



Last month we looked at Air Fuel Ratio (AFR) and explained what it is, how it is measured and how a fuel's content affects it. This month we'll concentrate on the actual purpose of the air fuel ratio and how and why we need to run different air fuel ratios at different parts of our engine's operating cycle, as well as looking at common AFR problems.

GOOD AND BAD AFRS

Every engine is different in what it requires to perform its fundamental tasks such as idle, cruise, accelerate and operate at full throttle perfectly and safely. However, there are some general rules that will get you into the right ballpark.

The optimum chemically correct air fuel ratio for a petrol engine is what is referred to as stoichometric (Greek translation of 'measure of the elements') mixture. This occurs normally at 14.7 parts air to 1 part fuel, based on normal unleaded petrol. At this ratio there is enough fuel present to provide sufficient energy to keep the engine running efficiently without using fuel unnecessarily, and there is also enough air to ensure a complete burn of the fuel in the mixture at that point.

Stoichometric fuelling is also referred to as 'Lambda 1.00'. (Lambda is a whole subject in itself, see last month's article for more details.) Any increase in the richness of this mixture reduces the Lambda number, so 0.90 Lambda is richer than stoichometric and 1.10 Lambda is leaner.

This clean and chemically perfect mixture of 14.7:1 is usually favoured by most manufacturers for 70% of running modes such as idling and cruising as it presents us with the cleanest exhaust emissions and is catalyst friendly. As technology evolves we're finding more ways to remove by-products of consumption from the exhaust both mechanically and chemically, so this figure is reducing as we find ways to run an engine using less fuel without polluting the atmosphere. For 90% of cars built in the last 20 years this figure can be regarded as correct for light throttle cruising on narrow band Lambda sensor-equipped vehicles.

Be aware that it is common for some Hondas to run leaner than Lambda 1.5 at cruise and certainly the newer GDI (Gasoline Direct Injection) systems are allowing us to run at Lambda 2.0 now.

CHANGING AFR FROM LAMBDA 1

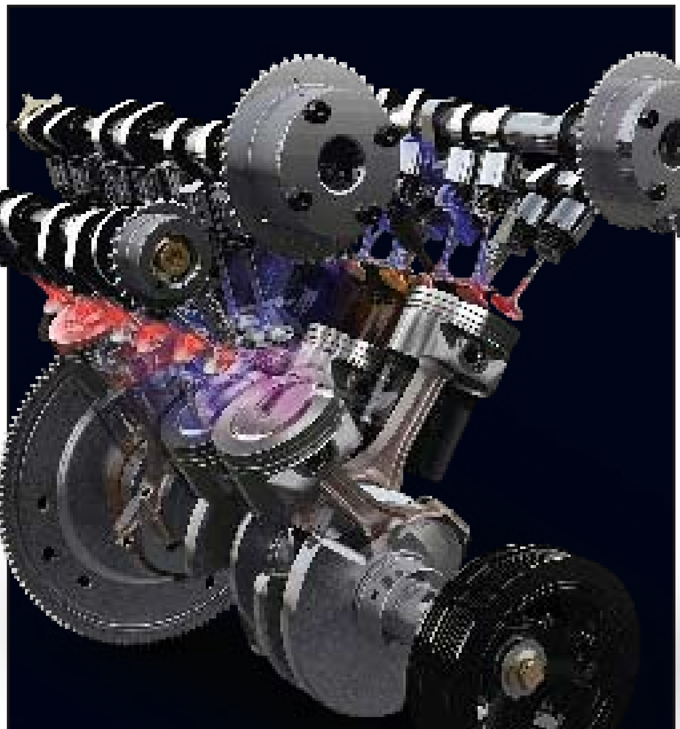
Although we mentioned that the Lambda 1 figure achieved the most efficient burn, sometimes we need to run richer to make more power. Remember using a Bunsen burner in chemistry lessons? By closing the air hole on the burner, you achieved a yellow licking flame, known as a safety flame. By opening the air hole up, the flame changed; as the air supply was increased, the intensity and ferocity of the flame rose until a roaring blue flame was achieved that was much hotter. This school chemistry class was an introduction to air fuel ratios!

With the yellow licking flame, a rich condition is generated where more fuel's available than ideal for good combustion. With the roaring blue flame, a different mixture of air and fuel resulted in a far hotter burning and higher intensity flame. The energy harnessed by our engine with these two differing mixtures is quite dramatic and has a noticeable effect on the engine's power output per revolution. It is reasonable then to say that we generally richen our mixture from stoichometric to achieve more power per stroke.

The other main reason we alter the mixture is for thermal management. The combustion process generates substantial amounts of heat, a lot of which is absorbed by the cooling system, but a large proportion of it is dumped out into the exhaust on the exhaust stroke. The temperature of this exhaust gas is known as EGT (Exhaust Gas Temperature) and measured with special thermocouples that can withstand in excess of 1000 degrees Celsius!

Adjusting the air fuel ratio your engine is operating at is like adjusting the air hole on the Bunsen burner, we do it to adjust the intensity of the combustion when we light the mixture. Generally, richer than max power will give a cooler burn, and leaner will burn hotter. However, there isn't a linear scale to this and as we lean off towards stoichometric it starts to invert, but you get the idea.

Correct AFRs are crucial to how an engine performs



Making modifications to an engine will affect the AFR

WHAT DOES THE AFR CHANGE TO?

Let's assume we are dealing with a naturally aspirated petrol engine on throttle bodies and a free-flowing exhaust system. We have established that for emissions and economy, the idle and cruise AFR will be around 14.7:1 AFR (Lambda 1.00) or in many cases leaner for maximum economy. As we start to accelerate and generate extra load on the engine, we will need to increase the fuel delivery to match the additional air being drawn in, and to enrich the mix to provide more engine power.

With the throttle pedal all the way down and running on normal unleaded fuel, we can expect to achieve peak power with an air fuel ratio of around 12.5:1 (Lambda 0.85/0.86).

Because the air is freely entering the engine through the throttle bodies and exiting through the free-flowing exhaust with little obstruction, the heat created inside the engine dissipates quickly. However, if we ran the same engine in a turbocharged configuration, passing the exhaust gases out through a turbocharger would pose a restriction in the flow.

To ensure we don't generate excessively high temps inside the engine's combustion chamber, exhaust ports and manifolds, we would need to enrich the AFR to in excess of 12:1 and often into low 11s. This will decrease the burn temperature and bring everything back into acceptable limits. Unless there is a particular restriction in the exhaust manifold or system, enriching the mixture beyond this point will usually start to reduce the power output substantially with little cooling effect. It will also waste fuel. That said, there are various well-known high power production cars running 10:1 and richer as standard.

"MISFIRES GENERALLY HAPPEN EARLIER WITH RICH MIXTURES UNDER FULL POWER."

WHY THE AFR CHANGES

As we perform modifications to a vehicle, we can drastically alter the air fuel ratio, intentionally or otherwise! Here are a few examples:

Lambda sensors allow ECUs to alter the AFR by measuring the oxygen content of the exhaust gases

Sensor faults: Any faults that feed the engine management incorrect information can lean out or enrich the amount of fuel delivered. The biggest culprits are air mass meters, coolant temp sensors and Mass Air Flow meters.

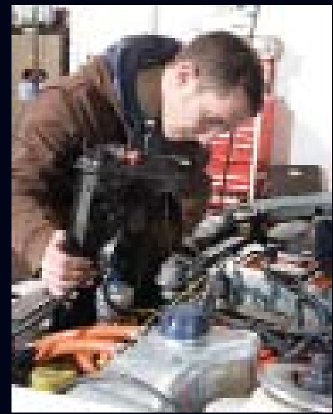
Fuel system failures and damage: Squashed any fuel lines recently? Are you sure your fuel filter is clean and free flowing? All these items affect your AFR if they are not up to scratch and operating to specification.

Exhaust changes: The exhaust system fitted to most production vehicles is primarily focused around minimal noise and emissions. The restrictions posed by catalytic converters and silencers create a flow impedance to the exhaust gases and create what is known as 'back pressure'.

When the exhaust valve opens to vent the exhaust gases out of the combustion chamber there is less room for the gases to move in to so some of the gases remain in the cylinder. This leftover exhaust gas limits the amount of air that can be drawn in on the next engine rotation.

By fitting a larger diameter exhaust system without the catalytic converter and less silencers we can reduce this exhaust back pressure. However, if the vehicle was mapped with the original system, the fitment of the new could create a lean condition. By reducing the back pressure, more exhaust gas can be vented out and more air drawn in, without additional fuel to suit, which can cause the mixture to run lean.

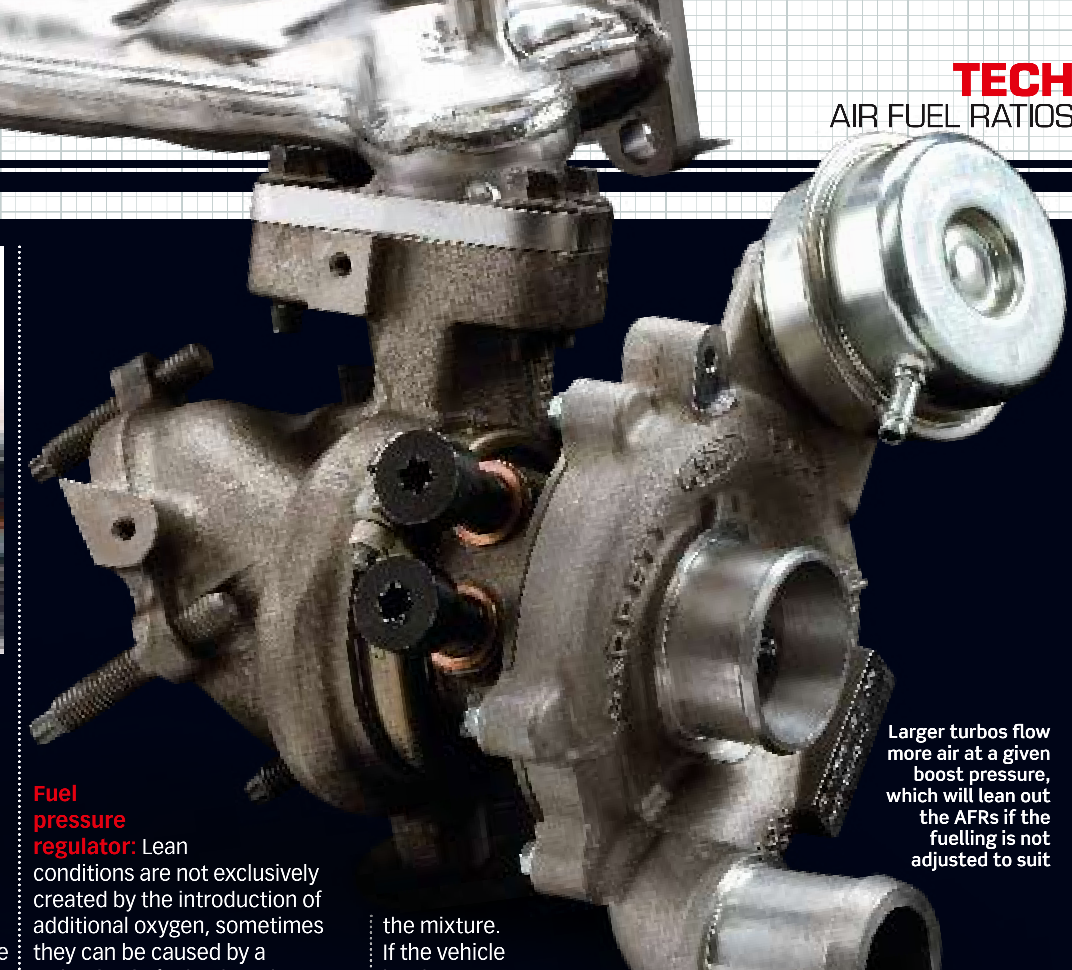
Larger exhausts lower back pressure, which alters the AFRs



Intercooler fitment (turbo cars): Most standard vehicle intercoolers are perfectly acceptable for standard boost pressures. However, when we start tuning vehicles and raising the boost pressure, we normally find that the factory intercooler can't keep up. Through a combination of standard intercoolers normally being made to a compact design and on a budget, it is common to find small surface areas and inefficient cores. This means that the air passed through the intercooler is unable to cool effectively and so we see an increase in the air charge temperature entering the engine.

As many of you will know, hot air contains less oxygen than cold so if the vehicle is mapped at this point, the air fuel ratio will be adjusted to create a suitable mixture of hot air and fuel. A logical progression in tuning the vehicle in the future is to fit a larger, more efficient intercooler. However, that excited test drive after fitting your new intercooler could prove both catastrophic and expensive!

A large, free-flowing and efficient intercooler will be more effective at cooling the air passing through it. In turn, the air entering your engine will be considerably cooler and contain more oxygen. All this extra oxygen is met with the same amount of fuel as per the mapping on the original intercooler and guess what? We have a lean mixture…



Larger turbos flow more air at a given boost pressure, which will lean out the AFRs if the fuelling is not adjusted to suit

Fuel pressure regulator: Lean conditions are not exclusively created by the introduction of additional oxygen, sometimes they can be caused by a reduction in fuel. When the vehicle is mapped, a base fuel pressure will be set on the fuel pressure regulator. The small nipple on the top of the regulator is connected to the inlet manifold and receives a pressure signal. This allows the regulator to increase the fuel pressure at the same rate as boost pressure enters the inlet manifold on a turbocharged car and will increase in approx half a bar under acceleration on an N/A car. If this pressure reference pipe becomes damaged or detached the fuel pressure will stay static and not rise when accelerating, or on turbo engines when boost pressure enters the inlet manifold. This will also result in a dangerously lean condition!

Boost pressure increase (turbo cars): While we all probably know better than to listen to that chap in the pub who assures us that it's a great idea to 'just put another turn on the actuator', let's consider why. There is a pattern to the causes of the air fuel ratio leaning out, which is the introduction of more air to the mixture. If the vehicle has been set up and mapped to run a particular boost pressure, then increasing that boost pressure will lean the mixture out by forcing more air into the combustion chamber.

There are a number of reasons that the boost could increase over its set level such as actuator/wastegate reference pipe damage, sticking wastegate or the rectification of a boost leak. A boost gauge is a valuable tool to keep an eye out for any unusual behaviour.

Bigger turbo-charger fitment (turbo cars): The standard turbo-charger most probably runs less than 14psi of boost pressure. As part of the tuning process we need to increase that boost pressure to move more air into the engine. As we increase the boost pressure, we increase the rotational speed of the turbocharger and can quickly over speed the turbocharger to the point where it is operating outside of its efficiency map. When this occurs, we don't produce much more power as the air temperature is raised and the oxygen content reduces.

The next logical tuning step is to fit a new turbocharger. With careful selection we can tailor the compressor map of the new turbocharger to suit the air consumption of the engine. By doing this, we can keep the turbocharger operating in its maximum efficiency zone for as long as possible.

However, running this new, more efficient turbocharger on the same mapping as your original turbocharger will again cause a lean mixture. If for example we ran 30psi of boost pressure on the old turbocharger and saw air temperatures of 60 degrees Celsius, on our new more efficient unit, we may see air temperatures more like 40 degrees Celsius. This reduction in air temperature, in the same way as the larger/more efficient intercooler, increases the oxygen content in the air and will lean out the air fuel ratio.

It is also worth noting that when we increase the physical size of the turbo, at a given boost pressure the larger turbo will flow more air than a smaller one. For example a T4 running 20psi will flow greater volumes of air than a T3 producing 20psi of boost. This increased amount will affect the AFR.

RICH FUELLING

We now know that richer mixtures produce cooler combustion gases than a stoichometric mixture. This is mainly down to the excessive amount of carbon that oxidises to form carbon monoxide and in turn produces far less heat than oxidising to carbon dioxide. This same carbon is the reason you can easily see if your engine is running richer than we've talked about simply by removing the spark plugs. As these are sat in the combustion chamber, if they are covered in thick black soot, it's a strong indication that excess fuel is being burnt.

Catalytic converters are designed to burn any unburnt fuel in the exhaust gases, so with an engine that is running rich we can expect its life span to be noticeably shortened. Misfires generally happen earlier with rich mixtures than with lean under full power. We can also expect Lambda sensors to become clogged sooner as well as heavy fuel bills and some loss in power.

If we run into the 9s we can expect a phenomenon known as bore wash where the unburnt fuel washes the oil from the bore walls, thins the engine's lubricating oil as it ends up in the sump and massively accelerates engine wear. Beware of oil that smells of fuel!

Incorrect AFRs can result in very costly rebuilds

LEAN FUELLING

Lean mixtures produce hotter combustion gases than a rich mixture when the engine is under load. Lean mixtures usually create a misfire condition easier than rich mixtures under cruise and idle conditions and also have a more noticeable effect on power output. However, the main killer is that a lean mixture can cause catastrophic damage by melting pistons and valves so should be avoided at all costs!

MANAGEMENT MATTERS

Some engines are more susceptible to the problems highlighted previously than others due to the type of management fitted. Generally there are two main types commonly used today. The first and oldest is speed density and the second, and containing the newest technology is MAF (Mass Air Flow).

Speed density uses a MAP (Manifold Absolute Pressure) sensor, ATS (Air Temperature Sensor) and a TPS (Throttle Position Sensor) to calculate its load. This load is measured against the engine speed and is mapped to suit the engine's specification.

The Mass Air Flow system uses an air flow meter with a heated wire inside. The wire is heated to a known temperature and measures how much current is drawn to maintain that heat as air is drawn over it. Coupled with an air temp sensor in the unit, this allows the ECU to calculate how much air has been drawn in. This forms the load against which the engine speed is measured and the fuelling calculated from the map.

What happens if we change the camshafts in two cars with the same engine spec, one running speed density and the other mass air flow?

"THE MAF SYSTEM USES AN AIR FLOW METER WITH A HEATED WIRE INSIDE"

As the new camshafts affect how long the valves are open and how far they open, they will probably cause more air to be drawn in to the cylinder. The speed density system will struggle to cope as the vacuum properties at idle will not be the same and the behaviour under load will be different. As this system cannot see airflow, only manifold pressure, the vehicle will probably run rich at idle and lean under load. A remap will be required to recalibrate the map to suit the new camshafts and ensure safe fuelling.

However, the mass airflow system will be able to cope better as the changes in airflow through the engine will be measured by the air flow meter. This will allow the ECU to recognise increases or decreases in air flow and trim fuelling to suit.

This isn't to say that MAF systems allow for 'fit and forget' engine modifications as the compensation will only be to a point and ultimately the air flow meter will 'clip out' when it reaches its maximum range limits. It is worth having the fuelling checked under load after the fitment of any engine mod!

Camshafts affect the amount of fuel/air entering the combustion chamber, so have a dramatic influence on AFRs

Table gives approximate idea of how air fuel ratios and Lambda numbers compare

Lambda	AFR
1	14.7
0.99	14.553
0.98	14.406
0.97	14.259
0.96	14.112
0.95	13.965
0.94	13.818
0.93	13.671
0.92	13.524
0.91	13.377
0.9	13.23
0.89	13.083
0.88	12.936
0.87	12.789
0.86	12.642
0.85	12.495
0.84	12.348
0.83	12.201
0.82	12.054
0.81	11.907
0.8	11.76
0.79	11.613
0.78	11.466
0.77	11.319
0.76	11.172
0.75	11.025