FEEL THE DIFFERENCE

This month Stu talks us through the differences between turbocharged and N/A engines. It's more complicated than you might think...

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, in the past Stu has worked for a Ford Rallye Sport dealer, a well-known fuel-injection specialist and various tuning companies.

Then seven 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.

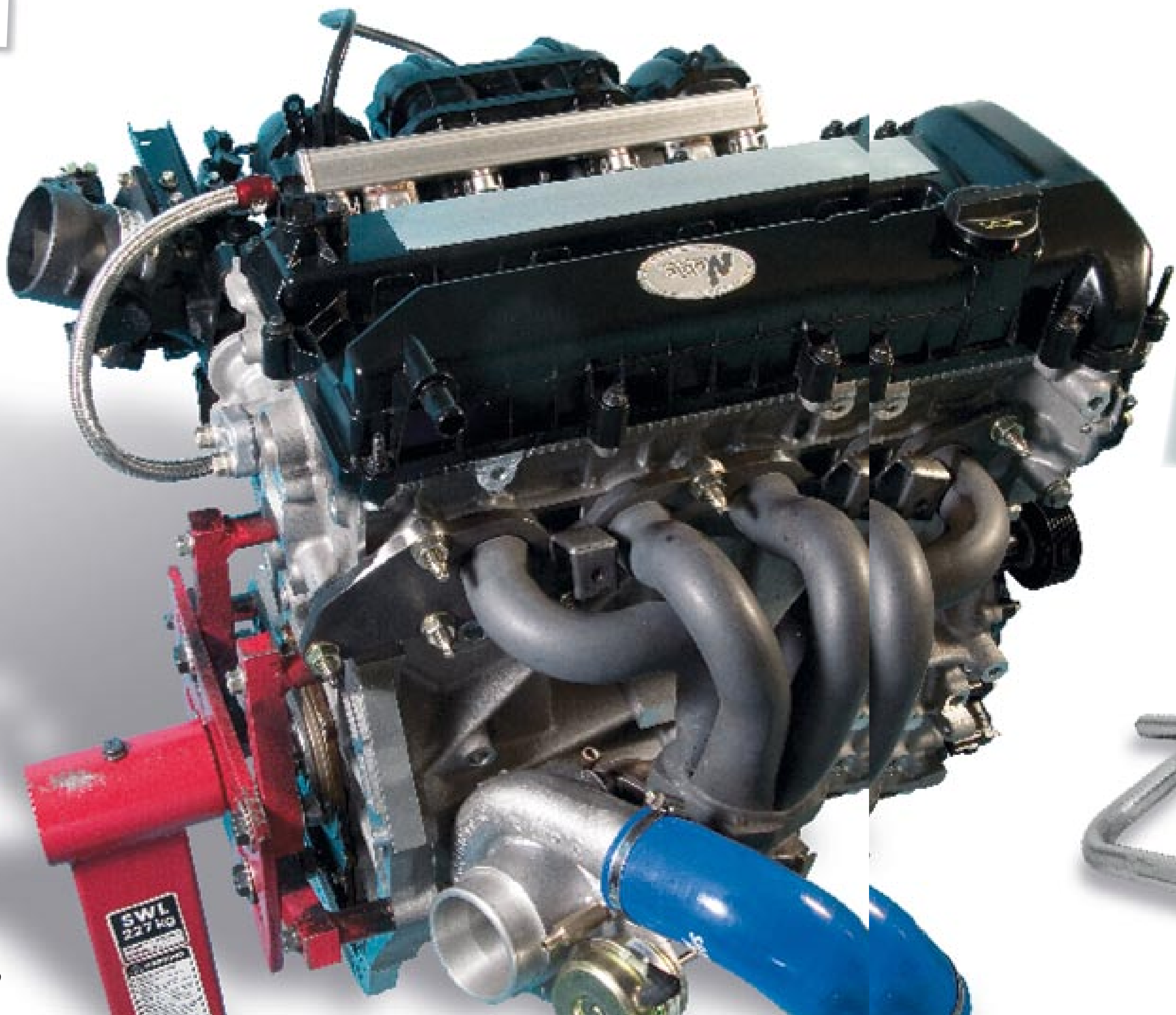
He's also jointly responsible with Webmaster, Petrucci for **www.passionford.com.** Started in 2003, it's grown rapidly from a few friends contributing, to one of the biggest Ford communities on the web. His new forum, **www.fordrsforums.co.uk,** is also up and running.

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 most importantly how they can be improved.

This month I want to look at the differences between a normally aspirated engine and a turbocharged one. I know from bitter experience that many of you think that the only difference between the two is the fact one has a turbocharger and one doesn't, but I assure you that nothing could be further from the truth.

Let's look at the majority of major differences in the two engines, using something like a 130bhp Mondeo or Fiesta Zetec as our theoretical example.

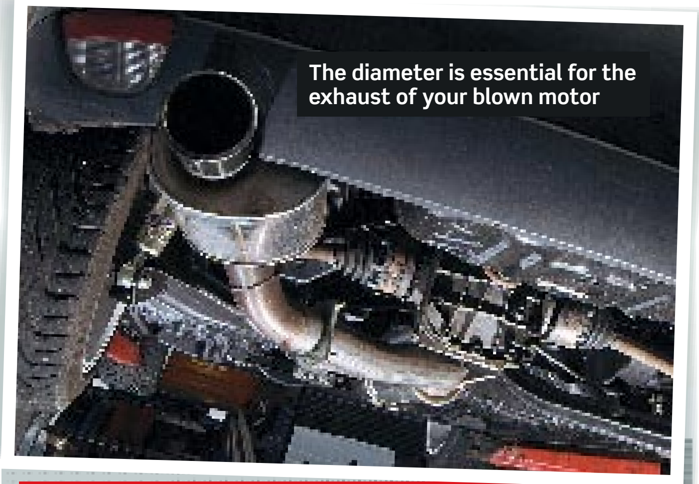
N/A manifolds are quite different to turbo applications



EXHAUST MANIFOLD AND TURBO

The first thing you need to deal with is obvious, and that's the fact that you need to add an exhaust manifold and turbocharger to your engine to turbocharge it.

The manifold on a turbocharged car is different to that of a normally aspirated engine and works on a different principle too as far as the primaries and collector are concerned, so take great care with this aspect and ideally entrust the work to people who are recognised experts in this field.



The diameter is essential for the exhaust of your blown motor

EXHAUST

Once your new turbocharger has pride of place on your shiny new exhaust manifold, your old exhaust is useless, or at least the part that connects it up to the engine or manifold is.

You now need one designed to mount onto a turbocharger, which will be in a totally different place. You also need to consider that your exhaust now has to get rid of more than just 130bhp. It has to allow the extraction to atmosphere of 250bhp worth of gas, so the standard 1.5in bore is no longer an option, you could really do with 2.5in or more.

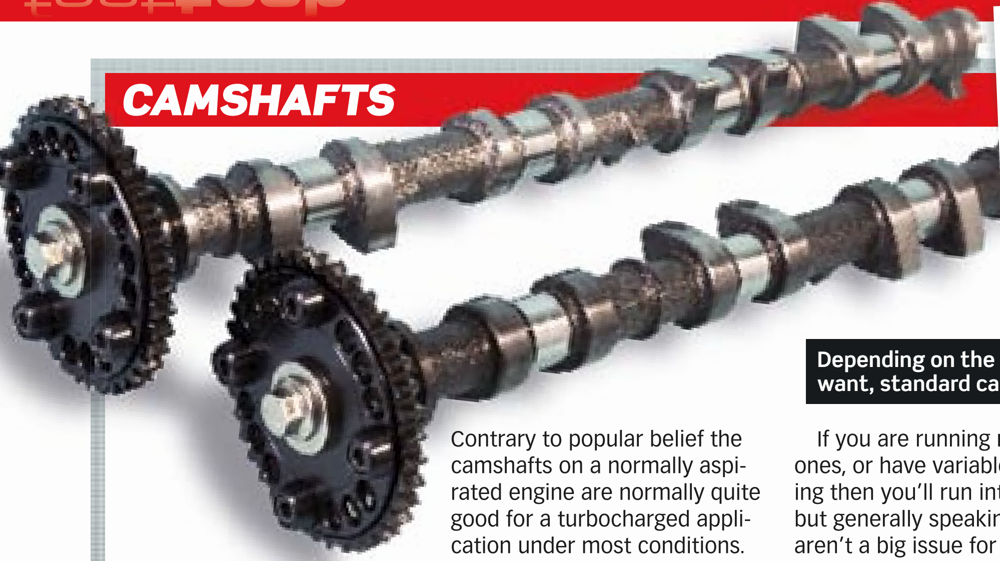
COMPRESSION RATIO

This is one of the most complex parts of the turbo conversion as it's one of the hardest to alter correctly and requires the head and sometimes the whole engine to be removed and dismantled. It also has a great effect on other aspects of the engine so needs to be finalised early in the conversion.

Compression ratio is such a complex subject that we cannot go into it fully here, but suffice to say you will probably need to change it for your turbo conversion to work properly as we tend to run lower compression on a turbocharged high-power engine. If you are looking for big power and reliability I would advise you to lower it.

There are numerous ways to do this such as decompression plates that fit between the head and block, you can skim the pistons making them shorter, bowl out the combustion chamber making it larger or use a combination of all these methods. However, the best way is to use a combination of chamber re-profiling and lower compression, better quality pistons.

CAMSHAFTS



Depending on the state of tune you want, standard cams are usually fine

Contrary to popular belief the camshafts on a normally aspirated engine are normally quite good for a turbocharged application under most conditions.

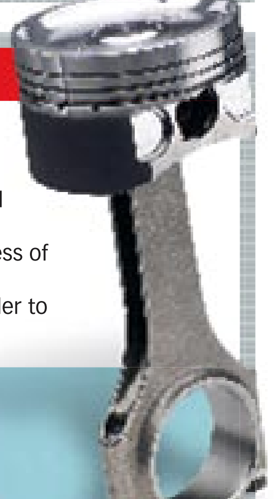
If you are running really wild ones, or have variable cam timing then you'll run into problems but generally speaking the cams aren't a big issue for an average turbo conversion and can be dealt with later on if you want to tailor your boost and power curves to better suit your intended application.

ENGINE MANAGEMENT

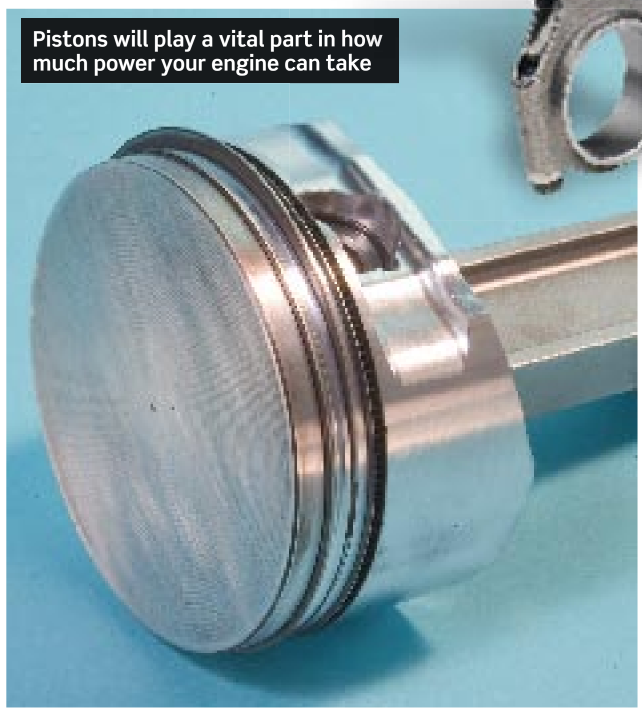
OK, we've added lots of lovely boost to our engine and are expecting it to make some nice extra bhp, and we know the engine will keep cool making it due to our cooling upgrades. However, to make that extra power we have to get our air fuel ratio nice and safe, and in most cases that job will be the sole responsibility of our engine's management system. It has to be aware of the boost and be programmed to deal with it. So, what will you have to upgrade just to allow extra fuel for the on boost conditions?

A custom mappable ECU is the best route to go for

PISTONS



The pistons are generally made of a different material or at a bare minimum they will be cast in a different way on a turbocharged engine, as they have to deal with vastly different pressures than their normally aspirated counterparts. Regardless of material or construction though, you will find you need to modify the pistons in order to correctly change the compression ratio.



Pistons will play a vital part in how much power your engine can take

HEAD GASKET

Head gaskets on some normally aspirated vehicles are not very good at all, simply because they don't have to be. Very often you will find a different material is used on the higher powered turbocharged models, so be aware that this issue may need addressing, although you will never know how tough the standard one is until you try it. My advice is if there is an uprated one on an existing turbocharged model then fit it, as the OE manufacturer didn't uprate it for a laugh and something to do, it was done as a necessity.

COOLING SYSTEM

This is one of the most overlooked things for some reason. The amount of cars I get in with turbo conversions and overlooked cooling systems is shocking. Adding bhp alone will add heat energy due to the inefficiencies of the internal combustion engine so we have to be able to lose this heat somewhere, ideally to atmosphere.

Don't overlook the fact that modern turbochargers almost universally must run water through their cores so you will need to design the plumbing for this so that it doesn't affect the flow around the engine too much. The water coming out of the turbochargers core is often superheated and will add considerable heat energy into our cooling system that we need to get rid of.

Sadly, I even see cars come in with the radiator cooling fans totally removed as the conversion company or person couldn't fit the fans and the turbo in the space available, so they just dumped the fans. Thankfully, nobody reading this would do anything so stupid as I'm sure you are all enthusiasts eager to do things right, and realise that radiators are air/air heat exchangers and need to have air flowing through the core to enable them to cool engines. That's why we fit fans, to keep the air moving when the car is not.

You need to keep the fans, especially when sat in traffic

FUEL INJECTORS

We've sorted the management and told the ECU to add more fuel on boost via a chip, some reprogramming or a totally different management system.

How do we know more fuel is actually available? You need some information about your original injectors and find out what they will flow for power. If they are not big enough you will need to change them to some that are larger, then you need to program the ECU again to ensure that the fuel is retained at the same level it was before the change until that extra fuel is actually required.

Throwing in big injectors without reprogramming will just end up with either a non-running or at best a very badly running engine.

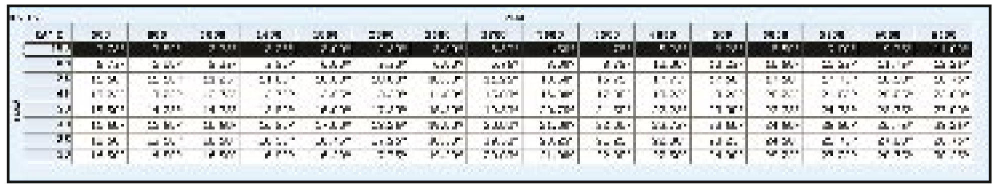
Make sure your injectors can flow enough fuel, else it'll melt

SPARK RETARD ON BOOST

As well as more fuel on boost, we need to program the ECU to retard the boost as the cylinder pressures get higher and higher. Generally speaking, the more boost you add, the less spark advance will be required. Get this wrong and you could say goodbye to the pistons in less time than it takes to get to fourth gear on your first-ever full power run.

It's not that simple at all, and there are a lot of other spark map changes to be done, but for the purposes of this article we are just simplifying. For more in-depth info, see my three-part management feature from previous issues.

Engine mapping is best left to the professionals



PRESSURE SENSING

On systems without an airflow meter (speed density systems) and presuming your management can accept input from a sensor that can see pressures over and above atmospheric, the first thing we must do is actually fit one, because you can be pretty certain the one you have will only be a 1bar sensor that can read up to atmospheric pressure.

If you try to use boost with the original one you'll discover to your pistons' peril that your ECU cannot see any boost and continues to fuel as though the engine was normally aspirated, thus only supplying the fuel for around 130bhp. Soon your engine internals will resemble a Mars bar in a furnace.

MAP sensors are needed to let the ECU see positive air pressure

FUEL PRESSURE

Have you ever considered how fuel, or for that matter, any liquid or gas flows from one place to another? Any gas or liquid will flow away from the highest pressure towards the lowest pressure.

Let's say we are running our injectors at 3bar of pressure in the fuel rail and that they inject nicely into our inlet runners... What happens to the flow then as the boost pressure in those runners increases to 3bar? At 3bar we would have equal pressure on either side of the injector and nothing would flow.

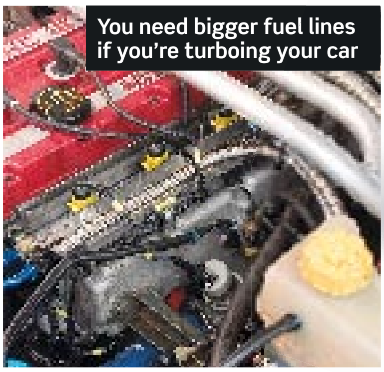
As the boost goes up our injectors flow less and less. So, how do we fix that? We swap our fuel regulator to one that increases pressure in a linear or greater fashion the more inlet pressure it sees. Usually we run 1:1 meaning for every psi above atmospheric pressure we apply to the regulator, it will increase the fuel pressure by 1psi.

As an example, a rail that runs 3bar at atmospheric pressure, will run 5bar if it is used with 2bar of boost, this keeps the differential pressure across the nozzle the same from atmosphere right up to as much boost pressure as the regulator can deal with, normally about 2.5bar in my experience.

FUEL LINES

We have our fuel pump supplying the volume of fuel, and the injectors are ready and waiting to supply that fuel to the plenum at the correct fuel pressure to ensure atomization in our highly pressurized inlet.

Great news, we are all done now then? No, how does the fuel get from the pump to the new injectors? The lines are far too small on many normally aspirated cars so we need to uprate the lines too. How big we go depends on the power we want, so take specialist advice or risk doing it twice, and don't forget the return to the tank line. If that is too small our fuel pressure will be stuck too high as the regulator can't bypass sufficient volume of fuel to maintain the required pressure, not good news at all on our huge new injectors.



You need bigger fuel lines if you're turboing your car

FUEL PUMP NEEDS TO BE UP TO IT

Things are looking good now. We have big injectors and management to cope, and we have sorted the fuel regulator so that it increases the pressure as we run more boost, so what next? Well, we have to head back down the line to the fuel pump. The fuel pump on your car may not be able to supply that amount of fuel for the bhp you are running, and it most certainly may not be able to do so at a couple of bars extra pressure. Time for yet another upgrade...

Make sure the wiring is up to the job, too

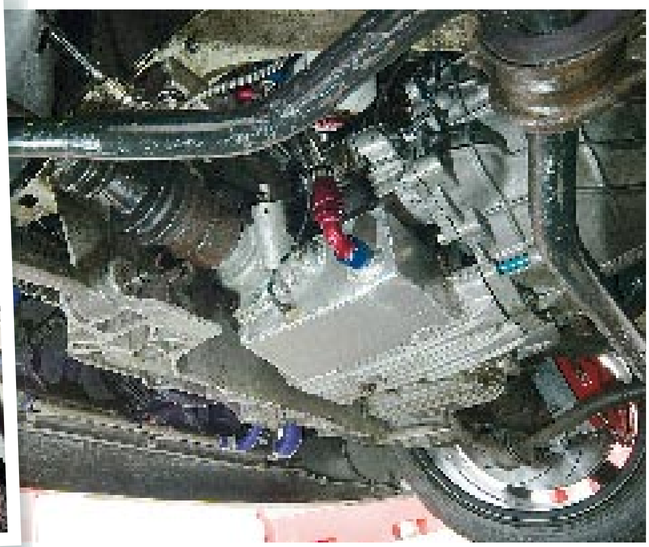
LUBRICATION FOR TURBO

Turbochargers do require a good supply of oil under very high pressure to ensure lubrication of the journal bearings at high turbine speeds and core temperatures. Have you considered where you will get this oil supply from?

Nine times out of 10 we use the oil pressure switch drilling and fit an adaptor here to allow us to supply both the switch and our oil feed, but I can think of a couple of examples where this isn't possible, so think ahead.

You also need to bear in mind that not only do we need to get oil into the turbo we need to get it back out too, and down to the sump again. This requires a tap into the sump of suitable bore and angle so as not to restrict the oil return path, as doing so will cause oil to be forced past our turbine seal, leading to smoke. Even the big boys get this wrong at times as Ford proved when it got this design wrong on the early Fiesta Turbos and had to uprate the oil return pipe to ensure reliability.

You need a high-pressure oil feed to keep your expensive turbo going strong



BREATHER SYSTEMS

When you increase the power of an engine, you invariably also increase the piston ring blow by, which means we have a certain amount of air to process and remove from the crankcase if we don't want all our oil seals to fail. Normally, an engine's breather system will simply link the top and bottom of the engine with a series of pipes and route the resultant oily air mixture into the inlet plenum for re-digestion into the combustion process, as that's the greenest way of doing so.

The problems you will face with this method are numerous, but the main problem is that your normally aspirated breather system pipework isn't normally of sufficient bore to move all the gas required on a high power engine, also the normal system is easily overcome by excess oil on a high-performance engine that throws its oil around in the sump a lot. So, you will often need to add another port to the opposite side of the block to deal with oil surge under hard cornering.

An oil separator is advised to allow the mixture to enter a canister as a heavy oil and air mix. The canister then separates this oil/air mix and sends the air to the atmosphere or back to the inlet of the engine. The spare oil that was separated is then returned into the sump, thus lowering oil loss quite dramatically.

OIL COOLING

How many of you are aware of, or have ever considered, the fact that oil is the engine's primary coolant? All the surfaces of your engine that generate any heat such as bearings and bore walls etc are lubricated and cooled directly by the oil.

The oil transfers this heat to the block and sump etc. The water jacket then absorbs some of this heat and transfers it away to the radiator to be radiated back to atmosphere.

Get yourself an oil temperature gauge and monitor it to ensure you aren't running the oil too hot because of your turbo and extra power generation. If you are, time to look at one of the various oil cooling options available.


Oil coolers are a good idea to help keep the engine cool

INTERCOOLER

It looks like the management and fuel system are sorted now and we are safe to turn the boost up a little and see what our new powerplant can do. Well, maybe...

The amount of boost you intend to run will govern what we have to do about intercooling. If you're looking for just 3 or 4psi you will be fine.

However, if you want more than that, you should look very seriously into ways to cool down the air coming out of the turbo, you won't be making much power with air temperatures upwards of 100 degrees Celsius, so you will need to fit either an intercooler or a chargecooler.

See *FF* issue 262 for more in-depth information on the differences between chargecooling and intercooling and details of how it all works.


With intercoolers, bigger really is better

FUEL OCTANE

This sadly is one of the biggest killers for a DIY turbo conversion. People seem to forget that performance engines require performance fuels, and they continue to run their new high-power boosted engines on low octane shopping fuel and detonate it. High power engines without complex management incorporating active knock detection require the best fuel octane you can buy at the pump. Ignore that advice at your peril.

So there you have it, hopefully that will have given you some idea of the complexities involved in converting a normally aspirated engine to a turbocharged one. See you next month.

NEXT MONTH

We will look at exhaust gas temperature, how it's measured and why it's important.