WHAT IS MAPPING?

PART 4 In the final part of Stu's mapping series he reveals how to get the most from your engine's modifications.

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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.

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.

Even cam and exhaust changes on a NA Zetec will require an ECU remap

HOPEFULLY you have read and digested the contents of the first three mapping features (*Fast Ford* issues 253 254, 255) and are now ready and waiting for this final lesson...

This issue I intend to deal directly with the bottom line in tuning a spark-ignited petrol engine, and that is how to make your modifications work correctly with the engine by tuning the air fuel ratio and spark advance to suit.

Anybody can bolt a camshaft to an engine, or grind a bit of metal out of a set of cylinder head ports, and doing something like this will of course alter the airflow characteristics and indeed the air shifting capability of the engine, but it will also mean that you have altered its requirements for spark advance and fuel delivery, and how are you going to modify those?

Years ago, when we had carburettors, the system was actually quite self-tuning as the depression in the carburettor venture sucked in more or less mixture as required to a certain extent, and if it was wrong the keen DIY fan could screw in some new fuel jets and emulsion tubes and try again. Sadly however, for all its hi-tech bells and whistles, modern management is actually quite poor at self-tuning for such dramatic changes, so you need to be able to get the engine management on your side before any of your modifications will work properly, and that's where mappers come in.

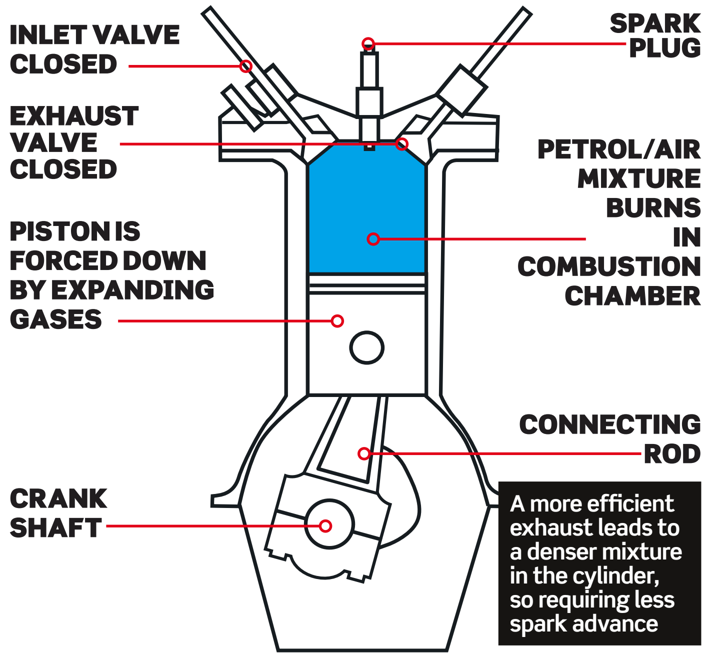
So, what do we normally have to change during a mapping job? Well, that varies according to the engine, but let's takes the 16-valve Zetec as a common example, as we map a lot of those.

On the 16-valve Zetec we would normally be concerned mainly with the fuel and spark maps at both idle and part throttle as well as at full throttle. They have separate spark and fuel maps for each mode of operation, as well as maps for torque limiters and rev limiters in some cases. As this is quite a complex topic, let's just look at what sort of mapping changes are required in straightforward cases such as a new camshaft, exhaust system and free-flow air filter.

SPARK ADVANCE TUNING

Let's say our theoretical engine is normally-aspirated and all that we have done to modify it is add a Fast Road camshaft profile, a free-flowing air filter and less restrictive exhaust system. You might think that these won't make a lot of difference to the mapping, but you'd be wrong in many cases. Worse still, some people think that freer flowing exhaust systems will always require more advance!

The truth is often surprising because the newer and more efficient exhaust you've fitted is leaving less exhaust gas in the cylinder on the exhaust's stroke due to improved scavenging, and we have less exhaust gas flowing back into the cylinder due to excess exhaust pressure. This leaves far more room in the cylinder to



A more efficient exhaust leads to a denser mixture in the cylinder, so requiring less spark advance

TIMES TABLES

Here are a few of the less commonly discussed tables we will alter in the course of mapping a car properly.

TRANSIENT MAPS
Since no current port injection system actually has the ability to achieve 100 per cent atomisation and absorption of the delivered fuel, we will always get a certain amount of fuel collected along cylinder walls and in intake runners.

This collection of puddled fuel and its effect on our fuel delivery system is permanently present and is known as 'Tau'. This Tau is a constant modifier of our fuel mixture as the passing air is constantly absorbing a little of it.

The ECU must therefore calculate its affect on our fuel delivery and constantly predict the extent in which the Tau volume will be changed based on how much and how suddenly we deliver more air with sudden throttle increases.

Commonly, going from light throttle to sudden acceleration will result in a dead spot in our power delivery, which is normally felt as a stumble. The stumble is dealt with by an acceleration enrichment map, which allows us to increase fuelling momentarily depending on rate of throttle change.

This fuelling increase decays with time as the Tau builds back into place and normal fuel operation is resumed. We often have to tweak this system if cams, plenums, throttle bodies or modified heads are fitted.

	RPM									
Load	825	1025	1450	1875	2300	2866.667	3433.333	4000	5350	6700
5.000	5	5	5	5	5	5	5	5	5	5
1.000	5	5	5	5	5	5	5	5	5	5
0.899	5	5	5	5	5	5	5	5	5	5
0.699	5	5	5	5	5	5	5	5	5	5
0.500	5	5	5	5	5	5	5	5	5	5
0.400	5	5	5	5	5	5	5	5	5	5
0.300	5	5	5	5	5	5	5	5	5	5
0.200	5	5	5	5	5	5	5	5	5	5
0.149	5	5	5	5	5	5	5	5	5	5

ADAPTIVE MAPS
All modern ECUs of the past 10-plus years have adaptive abilities and these maps and systems allow the management systems to re-tune themselves constantly on either the fuel system alone, or commonly the spark system too. In some cases this is good, and in others it is bad. Each individual case will be assessed on its merits and the system either modified, or if the need arises, removed.

The most common reason for disabling one is normally because the spark adaptation system is listening to a louder more coarse sounding, modified big-boost engine and it has decided the sound it can hear through its knock sensor is engine detonation and as a result the ECU is retarding the timing and increasing the fuelling against our will when the noise is nothing more than a set of lairy cams and rattly forged pistons.

Either way, adaptive mapping must be disabled before we can map a car properly as its self-tuning features fight us when we are trying to make corrections. We must disable it to map live so that we know the base fuel and spark maps are 100 per cent correct before we re-enable the adaptive programs to allow the ECU to keep the engine tune correct in all weathers and altitudes.

pack in more air and fuel, thus increasing the mixture density and therefore requiring less spark advance.

Another side-effect of upgrading the exhaust system is that, as previously mentioned, the mixture in the cylinder now contains fewer exhaust gas molecules and since the fuel mixture in the chamber is now less polluted with exhaust gas we will normally find that the flame front through the combustion chamber is actually burning faster, which yet again calls for less spark advance…

This is before we complicate matters by examining what effect the camshaft has had, and that depends completely on its profile and the amount of overlap it has. (More overlap almost always requires more advance due to exhaust gas pollution of your inlet charge. See *Fast Ford* issue 244 for more details.)

NUMBERS GAME
So, how do we actually get to the correct figure with spark advance? Well, it varies according to technique and available equipment and often comes down to experience. The correct amount of spark advance for any given engine/load combination is 'the minimum amount of spark advance to get the most amount of work done'. The term for the point where most amount of work is done is known as MBT (Maximum Brake Torque).

It's quite common for people to over advance their engines in the quest for maximum bhp, and this results in holed pistons and sometimes broken rods. The correct way to tune your spark map is to load the engine at the required speed and carefully advance to the point that we no longer see improvements in power output, or pulling power if road mapping with a G-meter.

You will often find that going further than this point can actually result in a loss of power and not the engine detonation that some people seem to think is the only result of too much advance… Many mappers mistakenly advance to the point of detonation and then retard the safe amount as you would expect, but on some engines this form of mapping simply doesn't work and you are quite a long way down from maximum torque, yet you're still way over advanced. You should always try to find the point of maximum torque generation and cap your advance there if possible.

It's also worth keeping in mind that turbo engines respond very differently to spark timing than their normally aspirated sisters. With a turbocharged engine you will normally find that when the spark is a little retarded the exhaust gas temperature naturally increases and if you get this right using sensible, discreet mapping you can use this phenomenon to actually improve the turbocharger's spool up time and thus increase the boost pressure the engine sees, gaining you more area 'under the graph' so to speak.

Sadly, the reverse is also true, and if we expose a turbocharged engine to excessive spark advance we not only drop bhp due to what's happening in our combustion chamber but we also lower the efficiency of the turbocharger due to reduced heat output to the turbine wheel from our exhaust gas.

Another downside to running too close to maximum advance is that the engine will now tolerate very little change in atmospheric conditions or even fuel octane. A 10 per cent increase in air density could easily result in a fuel mixture lean enough to destroy the engine, where as a 1 point drop in fuel octane could see your shiny new pistons looking like a Mars bar in a furnace! Care has to be taken to ensure your spark map is safe at all points and pressures.

Engines fitted with airflow meters can sometime compensate for airflow changes due to less-restrictive filters and exhaust systems

FUEL MIXTURE TUNING
From spark advance let's move on to the fuel requirements of a modified engine as these are somewhat simpler to deal with in most cases. The extra air flowed through your less restrictive air intake and exhaust systems will lean off most systems, but to what extent depends on the system.

Excess exhaust gas temperatures will eventually lead to this…

Engines with air flow meters (MAF systems) can compensate to a certain degree depending on how well programmed they are for such changes in the first place. Some are great, some are awful. Engines equipped only with map sensors (speed density) are in trouble and due to their very nature will definitely run leaner, providing the parts fitted do actually improve airflow. (For the reason why, please see *Fast Ford* issue 248.)

If we take the same camshaft, intake and exhaust system mods on the Zetec as we did for our spark tuning theory, we would see that flowing extra air into and back out of the engine has improved its volumetric efficiency for the reasons we stated earlier. Now, if the engine were running at 12.5:1 AFR before, then it is quite likely that it is now running around the 13.0:1 mark instead, somewhat leaner due to your extra air.

This may well pick up some bhp on its own as the mixture is weaker, yielding some power, and it's burning at a different rate too, thus affecting our spark advance… Then, the camshaft has altered everything too. We may be better off, we may be worse, only a pro with good equipment will be able to tell you.

In my opinion, getting the fuelling correct is a lot easier than getting the spark advance correct as all we need to do is monitor our high-quality wideband Lambda display whilst operating the engine under the required conditions and just set it nice and safe via various maps. Simple as that, yeah? No, sadly not. For one, all engine operating conditions require a slightly different mixture for best results.

For example, we run leaner at cruise than we do at idle on most engines, and part throttle light acceleration can run far leaner mixtures than wide open throttle aggressive acceleration.

So, what other complications do we find with tuning the fuel? With spark we just tune for MBT, with fuel we tune with power, EGT (Exhaust Gas Temperature) fuel economy and emissions in mind, and we have various modes of operation to contend with which means differing mixtures to tune in, not to mention the problems that ruined gas speed due to camshafts can create with low-end performance, causing us to stray away from our own golden rules to afford a solution.

As a very common example, you'll find that most engines with big lairy cams simply won't idle correctly at stoichiometry and we will need to add about 10 per cent more fuel, which creates instant torque and stabilisation of the idle, but poor economy and perhaps legal implications for UK road use.

These same engines can perform fine with Lambda 1 (14.68:1) at cruise, yet require lots of fuel enrichment with sudden throttle openings to prevent hesitations.

Let's now split some different engine fuel requirements down into bullet points to more accurately describe the different operations you have in a day-to-day drive and how the fuel mixture changes according to these operations:

- Idle mixtures can be extremely lean. Most always below 0.5 per cent CO.
- Cruise mixtures can be even leaner, down to 16:1 and lower with most engines.
- Light acceleration mixtures can be anywhere from 15:1 to 13:1.
- Medium to heavy acceleration should never really be leaner than 13:1.
- Hard acceleration is tuned not just for power, but on the engines ability to control its EGTs. MBT may be achieved at 13:1, but we may have to richen right up to 11.5:1 to improve our chances of engine survival with spiralling EGTs.

GOLDEN RULES:
- Combustion can only occur between 8.0:1 & 25.5:1.

MAF TRANSFER TABLES
Most modern systems have this table and it is essentially an electronic airflow map whose airflow in kgph is mapped against the MAF meter's voltage output, so for every 0.1v increase in output, we can see the corresponding expected amount of airflow. Most MAF ECUs base around 80 per cent of their fuel delivery calculations on the MAF transfer table's data so the data must be correct, and if you have changed the volumetric efficiency of the engine at any point, then it won't be.

Volts	#mass/tic	Counts	lbs/min
15.999	0.00000137416	3273.3954	35.2349
5.000	0.00000137416	1023.0000	35.2349
4.500	0.00000097975	920.7000	25.1218
4.250	0.00000084796	869.5500	21.7426
3.800	0.00000063190	777.4800	16.2026
3.600	0.00000054715	736.5600	14.0295
3.399	0.00000047730	695.4354	12.2385
3.199	0.00000041536	654.5154	10.6503
3.000	0.00000035529	613.8000	9.1100
2.800	0.00000030221	572.8800	7.7490
2.600	0.00000025751	531.9600	6.6028
2.399	0.00000021792	490.8354	5.5877
2.199	0.00000018253	449.9154	4.6803
2.100	0.00000016670	429.6600	4.2744
2.000	0.00000014947	409.2000	3.8326
1.899	0.00000013504	388.5354	3.4626
1.699	0.00000010943	347.6154	2.8059
1.600	0.00000009778	327.3600	2.5072
1.500	0.00000008707	306.9000	2.2326

Any engine calibrator worth his salt will spend time perfecting this particular table to suit the engine's new requirements, as once this table is pretty much correct, we find that most other errors apparent in the management will slot into place more simply.

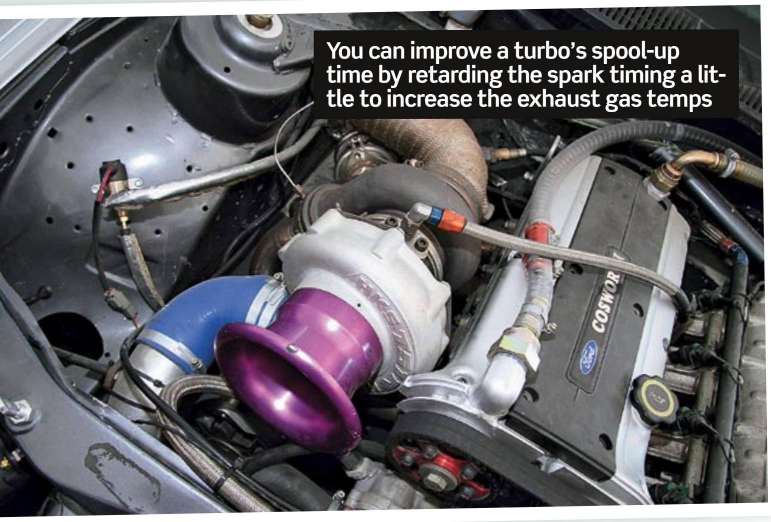
	Value
Max Load to Enter	0.799
Min Coolant for Fuel Shutoff	80.000
Min N/V to Allow Fuel Shut Off	150.000
Min RPM to Enter	800.000
Min VS to Enter	15.000
RPM Below to Turn Fuel On	400.000
Time at Closed Throttle to Enter	0.000
Time at Closed Throttle to Enter Extended	30.000
VS Below to Turn Fuel On	5.000

OVER-RUN FUEL SHUT-OFF AND DECELERATION ENLEANMENT
When you lift completely off your accelerator pedal you aren't looking for more torque, and as a result it's foolish for us to continue pumping fuel into the cylinders at this point as it will: a) keep engine speed from dropping as fast as it could do and b) waste fuel for no reason at all.

Correctly tuning this shut-off and enleanment system will also reduce the amount of fuel puddling present from adding too much fuel into the system with a closed throttle and no airflow. As such it should help stop any massive over-fuelling you commonly get if you don't adhere to this particular tuning method.

This over fuelling happens at closed throttle and commonly when you come back on the throttle or as your idle valve starts to operate. This is due to the sudden rush of air picking up fuel from that mystical 'Tau' fuel supply again… Lots of black and brown smoke at the back of the car is the normal result of over fuelling symptoms, and if it's really bad, the engine may even misfire at this point.

It's also worth noting of course that depositing rich, unburnt fuel mixtures into a catalyst will cause massive exothermic reactions that will significantly shorten its life. Due to this phenomena, some OE systems actually enrich ever so slightly on closed throttle in order to stabilise catalyst temperatures, but that is another story!



You can improve a turbo's spool-up time by retarding the spark timing a little to increase the exhaust gas temps

- Stoichiometry occurs at 14.68:1.
- Running leaner than stoichiometric is usually good for fuel economy.
- Running richer than stoichiometric is usually good for torque.
- Excess fuel can be used to control an engine's heat generation if necessary.
- Peak flame front speed occurs at around 13.0:1 and therefore this is normally the mixture point of least required spark advance. Either side requires more.

The above fuel examples are my personal golden rules and are aimed at broadly covering both normally aspirated and force induced engines as a whole, but the two different types of engine do run quite different fuel mixtures in the real world, so remember these numbers are just close examples for illustrating this feature.

FOOD FOR THOUGHT

There is a definite recipe for turning petrol and air into bhp and the results depend completely on the ingredients we are given to begin with. A suitable and safe balance must always be struck between maximum advance and fuel delivery and it is totally up to your particular mapper what avenue he chooses to proceed down with your particular engine.

If your engine has reached its power limit at 12.6:1, but we think more advance will bring out more power, we can richen up to 11.6:1 and try more advance and hope to gain more power with advance than we lost with excess fuel. The reverse may well be true too; you may gain more power by leaning the fuel and retarding the spark. As long as you remember that adjusting the fuel mixture also adjusts the spark advance required due to the burn speed changing you will do OK. Incidentally, you must also never forget that excess EGT will kill the engine in high gears, and that problem normally stems from either too little fuel, too little advance or excess exhaust back pressures.

Lairy cams create idling problems, usually sorted by adding more fuel

One last bullet point to remember when mapping is:

- All the ECU calibration in the world cannot add airflow to an engine (unless turbo or supercharged of course) so the ultimate air shifting capability (and thus power production) of the engine is down to your engine builder/designer, not the mapper.

So, there you have it, that's a brief description of what we get up to when we are out in your car with the laptop.

There is of course a lot more to it than that, but I hope I have covered at least the main systems that we modify for you when live-mapping.

NEXT MONTH

How to keep your Cosworth reliable. Stu reveals some of the most commonly-seen Cosworth problems and their respective solutions.

		RPM										
		750	1162.5	1575	1987.5	2400	3050	3700	4350	5000	5700	6700
TP	700	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921
	575	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921
	450	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921	1.9921
	350	0.7968	0.9453	1.1484	1.3828	1.5000	1.5000	1.5000	1.5000	1.5000	1.5000	1.3750
	250	0.7968	0.8281	0.9531	1.1171	1.3203	1.2968	1.2890	1.2734	1.2421	1.2031	1.0937
	200	0.7968	0.8203	0.8281	0.9765	1.1171	1.1484	1.1015	1.0703	0.9843	0.9062	0.7578
	150	0.7890	0.7968	0.8125	0.8515	0.9062	0.9296	0.9140	0.8828	0.8281	0.7187	0.5625
	100	0.7812	0.7500	0.7031	0.6406	0.6171	0.5781	0.5312	0.4531	0.3984	0.3515	0.2968
	50	0.6484	0.6015	0.5000	0.3515	0.2578	0.1484	0.1484	0.1484	0.1484	0.1484	0.1484
	0	0.1015	0.1015	0.1015	0.0703	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312

BOOST MAPS

If your modern engine has a turbo it will have numerous boost maps to tune. These maps will include peak over boost program maps that allow us to program in a careful over boost mid-range, as well as closed-loop boost maps that try to retain the same boost no matter what the weather or engine's conditions. Boost limits are another area we will often have to change.

		RPM					
		700	1000	2000	3000	4500	6000
load	1.600	510	510	510	510	510	510
	0.869	510	510	510	510	510	510
	0.600	510	510	510	510	510	510
	0.400	510	510	510	510	510	510
	0.200	510	510	510	510	510	510
	0.119	510	510	510	510	510	510

TORQUE LIMITING MAPS

Torque limiters on MAF-equipped cars can be interesting. Modern ECUs have the ability to calculate torque production based on air mass, engine speed and AFR and so manufacturers have used this system to limit torque in various circumstances. Sometimes it is used to limit power in first and maybe second gear for traction. Other systems have used it to keep a model's power down due to transmission inadequacies. We have the ability to move that torque limit level to whatever we wish, or even disable it altogether.

		TEMP										
		-40	-20	-14	6	40	60	76	90	106	120	187
Load	1.600	0.5390	0.6484	0.6875	0.7421	0.8593	0.8671	0.8671	0.8671	0.8750	0.8906	0.9218
	1.389	0.5390	0.6484	0.7031	0.7500	0.8593	0.8671	0.8671	0.8750	0.8906	0.9062	0.9296
	1.178	0.6562	0.7031	0.7500	0.7968	0.8671	0.8671	0.8750	0.8984	0.9140	0.9140	0.9296
	0.967	0.6562	0.7031	0.7500	0.7968	0.8828	0.8984	0.9062	0.9062	0.9218	0.9375	0.9609
	0.757	0.7031	0.7500	0.7500	0.7968	0.9218	0.9218	0.9140	0.9140	0.9296	0.9296	1.0000
	0.546	0.8046	0.8125	0.8203	0.8515	0.9375	0.9453	0.9453	0.9765	1.0390	1.0390	1.0000
	0.335	0.8203	0.8671	0.8984	0.9296	0.9375	0.9453	0.9531	1.0390	1.0390	1.0390	1.0000
	0.125	0.8281	0.8750	0.8984	0.9296	0.9375	0.9453	0.9531	1.0390	1.0390	1.0390	1.0000

FUEL AND SPARK CORRECTION FACTORS

During the extremes of temperature, an engine's fuel and spark requirements are normally quite different to its normal operating range.

The most common example is a cold engine that stumbles and hesitates when you try and accelerate. Often accompanied by an idle that surges up and down until the engine's warm. These problems are not normally due to faulty components, they are normally caused by maps that have not had enough attention paid to cold running, as the engine requires substantially more fuel and spark than it is getting until it's warmed through. One of the reasons is that our 'Tau' puddle doesn't actually evaporate into the air stream properly until the inlet is nice and warm.

Hotter ambient temperatures can lead to detonation through increased air intake temperatures, especially in force induced engines so these generally have aggressive spark and fuel subsystems in place to adjust the fuelling and spark maps to suit the faster burning hotter mixtures that have resulted from the ambient temperature increase. These systems all need careful tweaking to get our management system to do exactly what your modified engine requires.