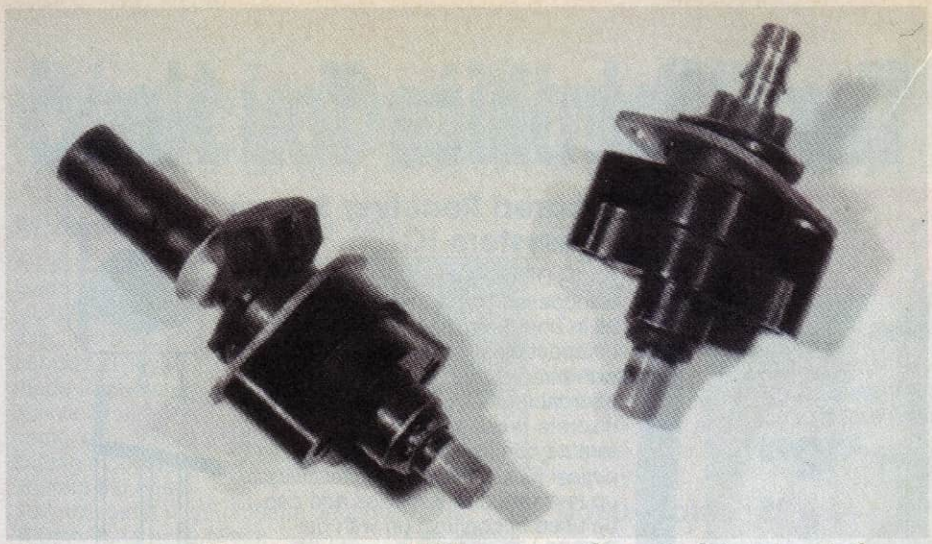
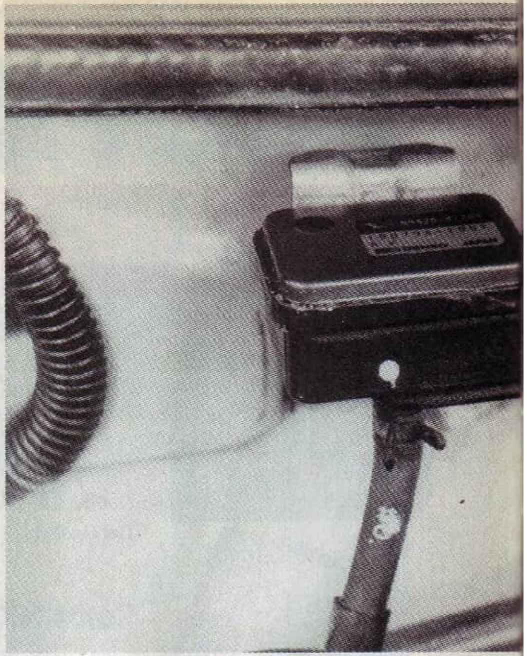




Most programmable systems use a MAP sensor as the main determinant of engine load and allow complete control over injector pulse widths. However, specifying a wide pulse width at high RPM may lead to a 100% duty cycle, necessitating the use of larger injectors (above).

A look at programmable fuel injection control

Australia leads the world in the production of cheap, fully-programmable engine management units. Used in both racing and high-performance road applications, these ECUs can be programmed to control both ignition advance angle and fuel injector pulse width.

By JULIAN EDGAR

The ease with which changes to injector pulse width can now be made means that air/fuel ratios can be exactly as desired in any part of the load and engine speed spectrum. But what ratios should be used? The complexity of injector flow rates and the duty cycle implications mean that there are traps present for the unwary!

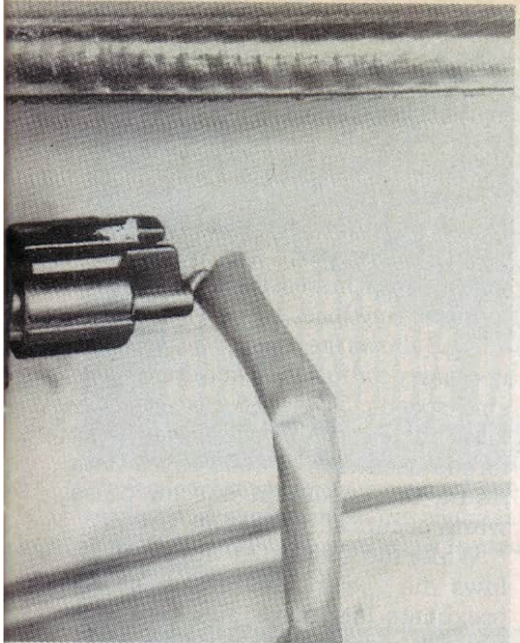
The proportion of air and fuel that is mixed together to form the combustible mixture is generally referred to as the air/fuel ratio. In practice, approximately 14.7kg of air is required for the complete combustion of 1kg of petrol. Another way of expressing this relationship is to say that about 10,000 litres of air is needed to burn just one litre of petrol!

However, this so-called "stoichiometric ratio" is not maintained under all engine operating conditions. The maximum torque and the smoothest operating conditions are experienced when a rich mixture of around 13:1 is used – an air/fuel ratio characterised by excessive exhaust emissions and high fuel consumption! Taking this further, the extreme rich mixture limit for a petrol spark ignition engine is about 7.5:1, while the lean limit for conventional engines is about 19:1.

In order that catalytic converters can work with maximum effectiveness, current engines use a stoichiometric mixture for most of the time. This is accurately achieved by the use of closed-loop control based on an exhaust gas oxygen sensor.

However, maintaining stoichiometric mixtures at all times would limit power, prevent adequate cold engine performance, increase emissions and reduce fuel economy. Because of this, mixtures other than stoichiometric are used at large throttle openings, during warm-up and during over-run conditions.

The air/fuel ratio which gives best results is influenced more by engine load than any other factor. Adam Allan (of Adelaide's Allan Engineering) is very experienced in tuning programmable engine management units for both race and road use. Taking the example of a turbocharged 2-litre engine, he suggests that the appropriate air/fuel ratio would be about 16-14:1 at the extremely low load of -50kPa manifold pressure, 14-12:1 (depending on



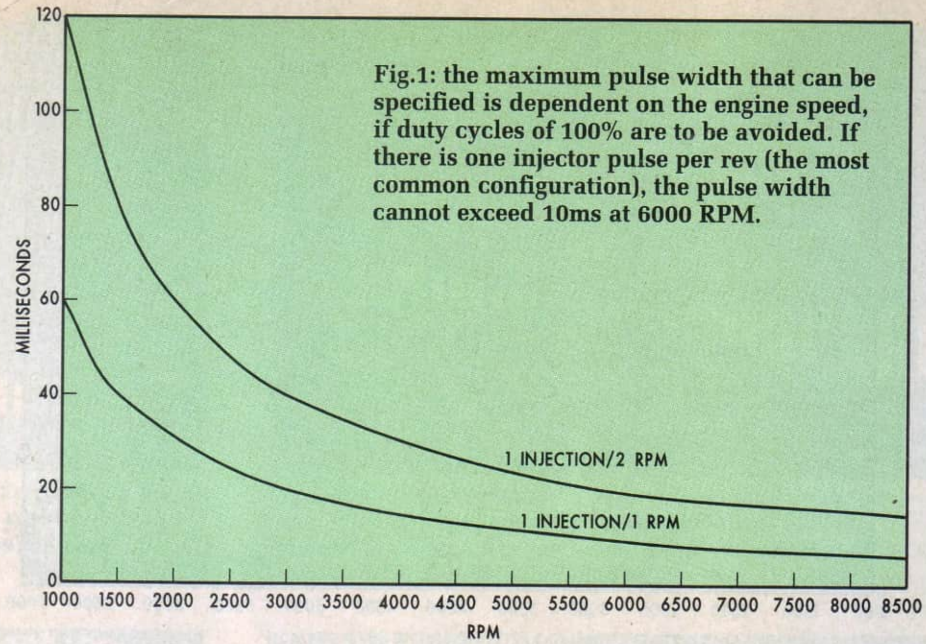


Fig.1: the maximum pulse width that can be specified is dependent on the engine speed, if duty cycles of 100% are to be avoided. If there is one injector pulse per rev (the most common configuration), the pulse width cannot exceed 10ms at 6000 RPM.

the torque output of the engine) at 0kPa , and about 12:1 at full load of +50kPa boost.

Other factors influence this relationship, with a standard VL Commodore Turbo using an extremely rich mixture of 10:1 at full throttle. The ECU has been programmed in this way probably so that there is a safety margin if the injectors become partially blocked or poor fuel is used, etc.

Injector control

Notwithstanding the changing air/fuel ratios and differing engine efficiencies at different loads, the amount of fuel used increases in proportion with the power output. In this respect, a fuel injected engine and one equipped with a carburettor are similar – more power means more fuel. However, a carby engine uses a continuous flow mechanism, whereby the fuel and air are being constantly mixed. On the other hand, in an electronically fuel injected engine, the fuel and air are mixed in the intake ports in a series of spurts; ie, the fuel is added to the air only when the injector is open.

The pulse width – or time that the injector is open – is measured in milliseconds. This determines the amount of fuel which flows from the constant-pressure injector. In practice, the injectors must operate quite rapidly. At 6000 RPM, for example, the engine's crankshaft is rotating at 100 times per second. This means that the maximum time available for the injection operation to occur during a single crankshaft revolution is 0.01 seconds, or 10 milliseconds.

If the pulse width is 8 milliseconds – and the injector fires once per engine revolution – then the injector will be open for 8/10ths of the available time. This ratio is expressed as an 80% duty cycle. If the duty cycle reaches 100%, as it would with an injector pulse width of 10ms at 6000 RPM, then the injector will be held open continuously.

Fig.1 shows the relationship between a 100% duty cycle, the engine speed and the firing frequency of the injector.

Once a duty cycle of 100% is reached, no further fuel can be added to the engine by the injectors (at least, not without changing the fuel pressure!). A further increase in the engine load would then result in an increase in the air/fuel ratio, giving rise to a possibly damaging lean-mixture condition. In this situation, larger injectors would need to be fitted.

However, the use of large injectors means that the precision with which fuel can be added at low loads suffers. A large injector will not be able to respond to very small pulse widths as accurately as a smaller injector, with inaccurate metering at low loads resulting in poor driveability and exhaust emissions. As a result of this, manufacturers often specify injectors which reach an 80-90% duty cycle figure during full power operation.

Note that while the duty cycle reaches its peak at the highest power output, the same is not true of injector pulse width. The greatest pulse width applied to the injectors is usually achieved at peak torque.

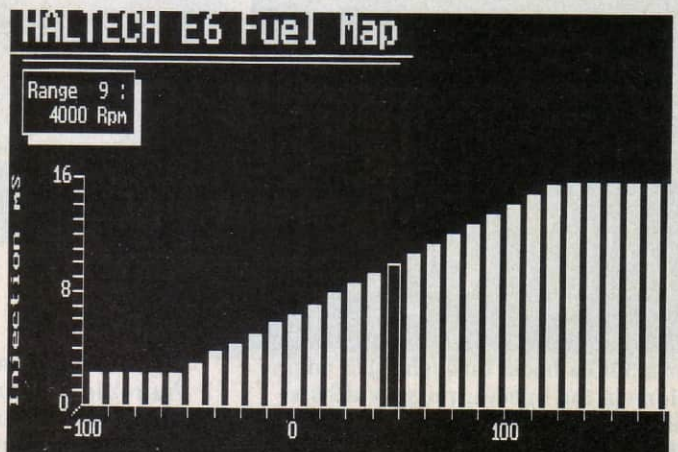


Fig.2: the Haltech E6 injector pulse width QuickMAP is configured in 500 RPM increments over the engine speed range using just four input figures. Further tuning is then necessary to obtain ideal air/fuel ratios.

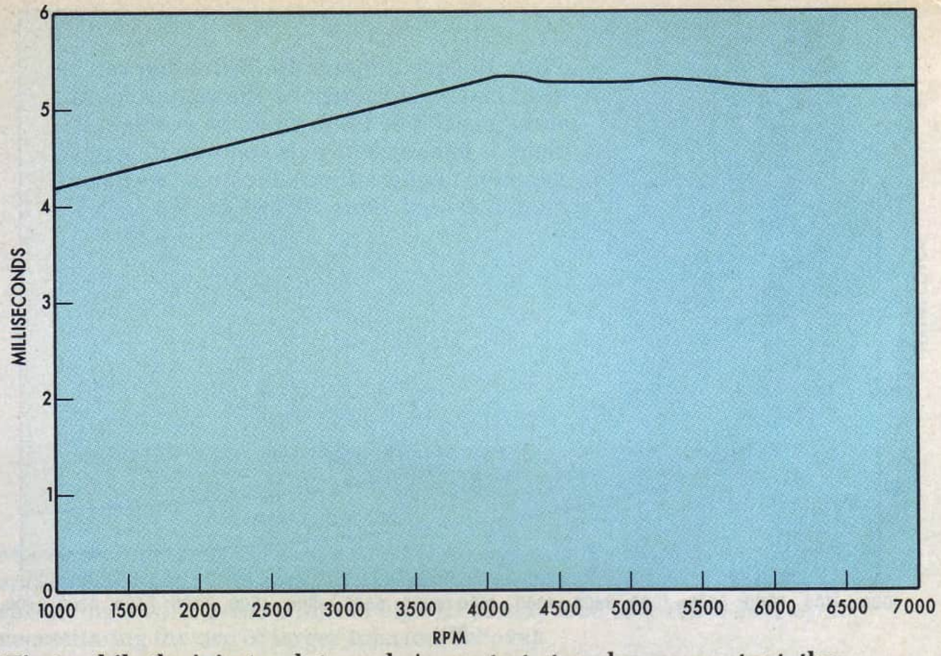


Fig.3: while the injector duty cycle is greatest at peak power output, the maximum injector pulse width normally occurs at peak torque, where the greatest amount of air and fuel is ingested in one stroke. This graph shows the injector pulse width for a turbocharged 2-litre engine in which the peak torque occurs at 4000 RPM.

To explain, the peak torque figure of an engine is reached when the greatest force on the piston is realised. This is associated with the maximum ingestion of air, which in turn requires the maximum amount of fuel per engine cycle. In a conventional piston engine, the peak torque value often occurs over only a very small portion of the wide-open throttle engine speed range. It is here that the maximum injector pulse width is required.

Programming fuel maps

As with its ignition advance angle system, Haltech – a major manufacturer of programmable ECUs – uses a proprietary QuickMAP approach to programming. This allows the very quick production of rough fuel maps for the whole load and RPM range. The QuickMAP process requires the input of the following parameters:

(1). Idle injection pulse width;
(2). Full load injection pulse width;
(3). Fuel percentage decrease at 2000 RPM; and
(4). RPM at which peak torque occurs.

From this data, the software calculates approximate fuel maps for all loads at 500RPM increments throughout the engine's speed range.

Fig.2 shows an example of a fuel map for a turbocharged engine which has been calculated by this QuickMAP approach. Note that this map is for different loads (the horizontal axis shows manifold pressure) at a constant engine speed, and so injector pulse width increases in proportion to increasing load.

Fig.3 shows the injector pulse width necessary for full load at different engine speeds. These figures were devised for an engine which had peak torque occurring at 4000 RPM. As a result, the maximum injector pulse width occurs at that engine speed.

While the QuickMAP approach allows the speedy production of approximate fuel maps, fine tuning is vital for optimal engine performance. Fig.4 shows a modified 3500 RPM QuickMAP which was produced by Paul Keen of Adelaide's Darlington Auto Tune for a Nissan FJ20 turbocharged engine. On this particular car, the maximum boost pressure was 50kPa (the position of the 'active' black bar), making it unnecessary to tune for loads greater than this figure.

Note the subtle variations in injector pulse widths which have been made, especially at loads around -50kPa. These low manifold pressures are obtained in cruise conditions around urban areas. The fine tuning is necessary because poor driveability at these throttle openings is very noticeable.

Fig.5 shows a fuel map for a Ford 289 V8 which uses Autronic engine

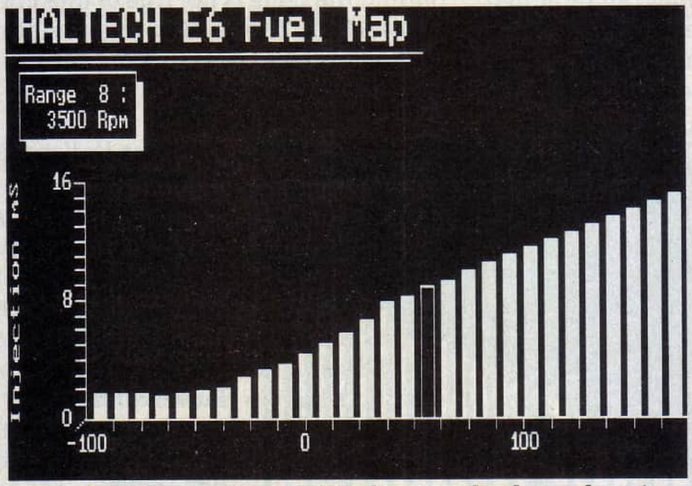


Fig.4: the fuel map for a 50kPa boost turbocharged engine. Note the small variations in the injector pulse widths at light load (-50kPa) conditions. This is necessary to ensure good driveability at light loads.

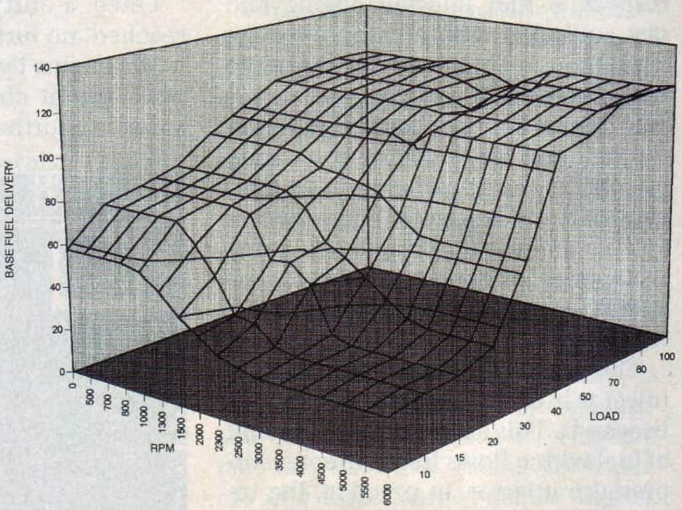


Fig.5: this fuel map for a Ford 289 V8 was drawn from Autronic tabular data using Microsoft Excel® software. The peaks and troughs are due mainly to resonances in the intake and exhaust manifolding.

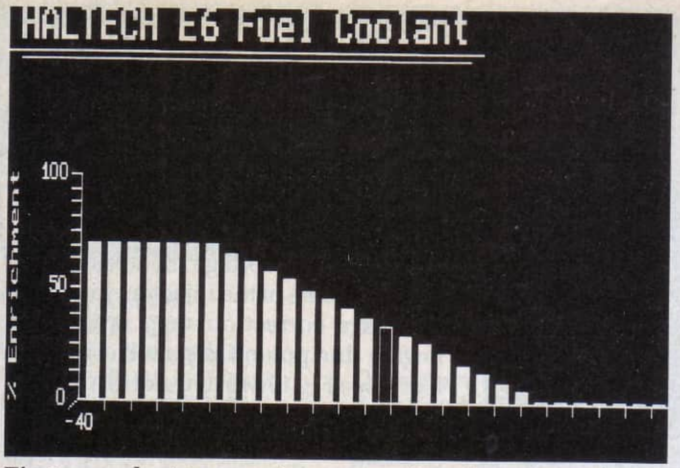


Fig.6: a coolant temperature correction chart. It can be regarded as equivalent to the choke in a carburettor engine. Note that the mixture is leaned as the coolant temperature rises.

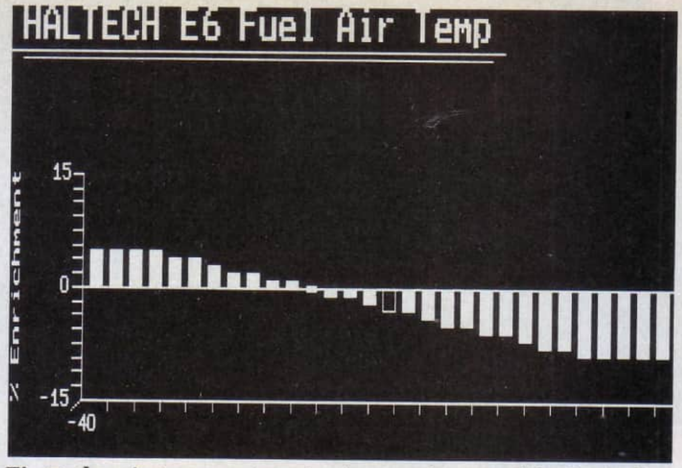


Fig.7: the air temperature is also used to modify the fuel map, with ±15% correction available. Notice how the mixture is enriched at the lower temperatures and is leaned as the intake air temperature rises.

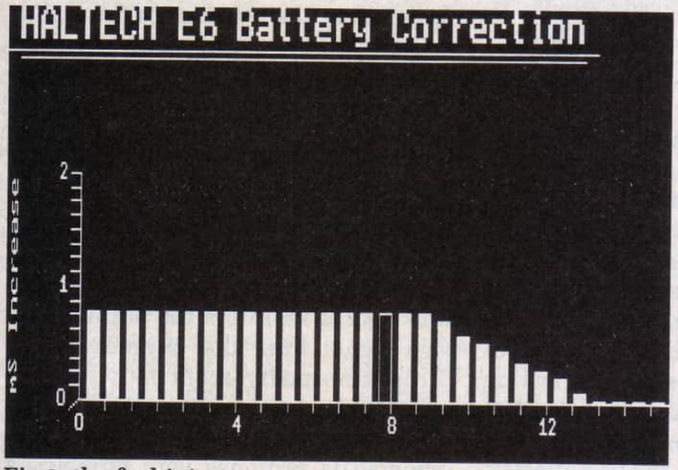


Fig.8: the fuel injectors react more slowly as the battery voltage declines and this is countered by increasing the injector pulse width.

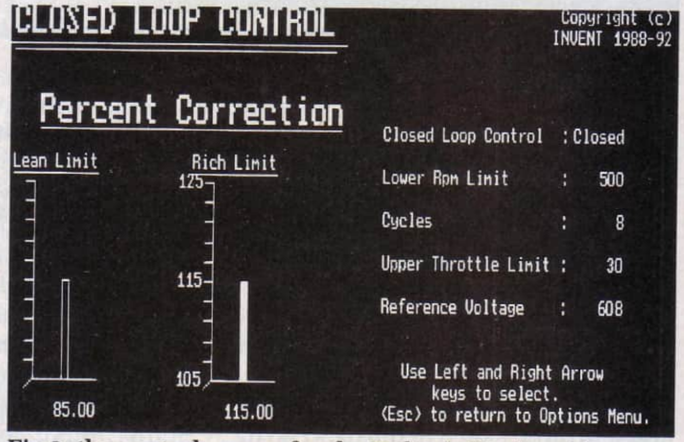


Fig.9: the control screen for the Haltech E6 closed-loop oxygen sensor feedback system. The times at which the system works in closed-loop, the amount of correction, and the speed at which it operates are set by the user.

management. This engine was tuned on an engine dynamometer equipped with extensive data gathering equipment and the resulting fuel map shows a number of "peaks" and "valleys". These occur mainly because of resonances in the exhaust and intake manifolds, which reduce the effective restriction at certain engine speeds and gas flows.

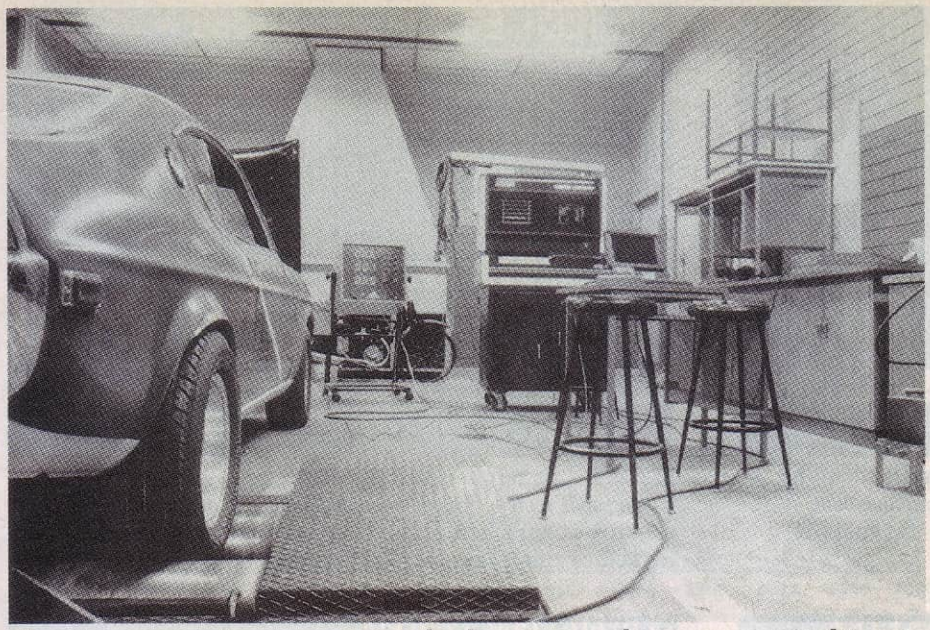
Note also that the pulse width values do not markedly decline past peak torque. This may be due to the use of relatively rich air/fuel ratios at high loads for this particular engine.

Injection correction maps

In addition to the base injector timing which is mapped using load and engine speed, a series of pulse width correction charts are also usually employed by programmable ECUs.

The Haltech fuel coolant chart

The Haltech engine management ECU. It can be programmed to compensate for coolant temperature, air temperature and the battery voltage, and has optional closed-loop oxygen sensor feedback control.

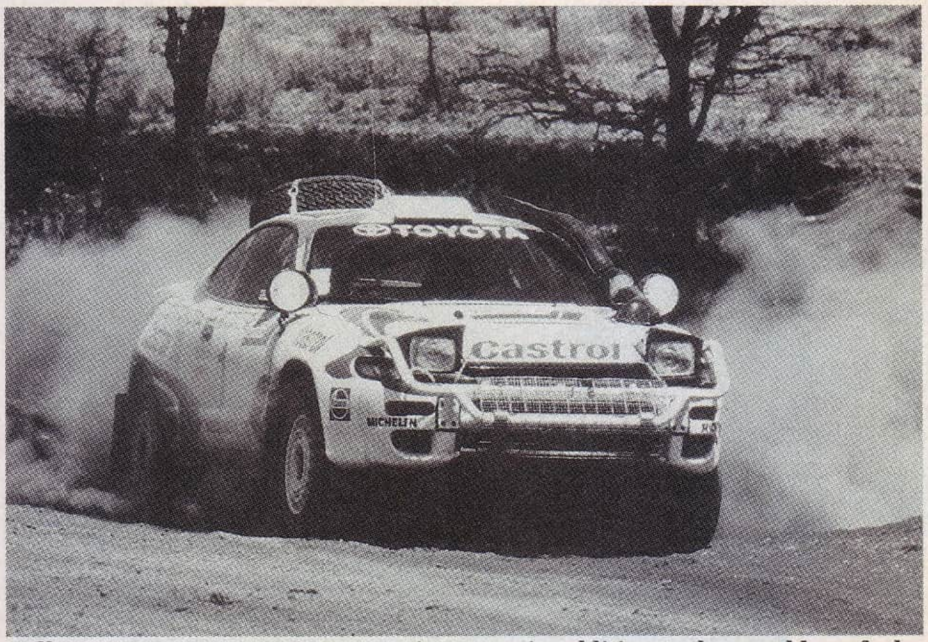


Chassis or engine dynamometers and exhaust gas analysers are required to set up programmable fuel injection ECUs.

shown in Fig.6 is an example. Effectively this map provides the equivalent of the carburettor choke. It shows temperature on the horizontal axis, while the percentage enrichment is shown on the vertical axis.

By the way, the Australian-produced Haltech system is sold around the world, which is why it can correct mixtures with temperature inputs down to -40°C! Each of the bars can be adjusted for height, depending on whether the engine requires warm-up mixtures richer or leaner than the normal setting shown here.

Mixture modification according to air temperature is also carried out – see Fig.7. At cold inlet air temperatures, the fuel atomises less easily, while the converse is true for warm inlet air temperatures. During testing of their Formula 1 turbocharged V6, Honda found that an inlet air temperature of 70°C gave the best specific fuel consumption. This map can be adjusted to give fuel economy benefits when the air inlet temperature is high. (Of course, the maximum realisable power will be decreased at high inlet air temperatures.)



Rally cars can use extensive correction maps in addition to the usual base fuel and ignition charts. Examples include enrichment of the mixture at times of low and high engine coolant temperatures, RPM limiting via fuel and/or ignition modification, and the correction of injector opening time on the basis of battery voltage.

Battery voltage correction

As battery voltage decreases, the response time of the injectors increases and so a correction map is used to negate this potentially deleterious effect – see Fig.8. Most, if not all, engine management systems have voltage compensation but not very many of them allow the user to manipulate the amount of correction. In a rally or long distance race car, for example, injector opening time compensation could be programmed in for voltages lower than the 9V limit of the standard map. This could be of benefit if the battery was slowly discharging due to an alternator problem, for example.

Along with a few other programmable systems, the Haltech E6 can be set up to use the feedback input of an exhaust gas oxygen sensor – see Fig.9. Used only at light throttle openings, the system monitors the output voltage signal from the oxygen sensor. This is normally about 1V when the mixture is rich and close to 0V when it is lean. The sensor is designed to change its response very quickly as the mixture passes through the stoichiometric ratio.

Closed loop control is user-optional with the Haltech system and can be disabled if, for example, the vehicle is to be used in a pure race application. The lowest engine speed at which closed loop control will become functional is user-specified, with this a requirement because some engines will not idle satisfactorily with stoichiometric air/fuel ratios.

The number of cycles through which the engine passes before correcting the mixture can be set in the range from 4-10, with the default being eight. The throttle opening angle after which the system will go into open loop is also definable, with a 30% figure being the default. Finally, the oxygen sensor reference voltage can be set, with the vast majority of sensors having a 600mV output at the stoichiometric air/fuel ratio.

Acknowledgements: thanks to Allan Engineering (08 522 1901) and to Darlington Auto Tune (08 277 4222). **SC**