FOUR-STROKE
PERFORMANCE TUNING

A. GRAHAM BELL

Second edition

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Preface

Practically no private owners, and only a few workshops where race engines are prepared, possess dynamometers. Consequently experiments in tuning usually must be conducted on a trial and error basis, which may have unfortunate results if the work has been wrongly conceived or executed. This book represents an endeavour to fill the gaps in the enthusiast's and race engine builder's knowledge, or to extend an acquaintance with the subject considerably further.

The range of performance equipment available for almost any car or motorcycle is staggering and often the claims made in advertising various items of equipment are equally staggering. Obviously there must be certain principles, applying to almost any engine, that will, if closely followed, bring good results. I believe that this type of information should be available to the tuner, to enable him to choose the best equipment and the best combination of modifications to suit his needs. With this in mind I have attempted to relate these principles in non-technical English and to illustrate them using many diagrams.

While I have endeavoured to make this work as complete and as comprehensive as possible, undoubtedly there will be questions that I will have overlooked and left unanswered. On the other hand there are certain to be times when the reader may feel that I have dwelt far too long on a particular point. I apologise for this. However, in spite of these possible failings I am sure this book will be found both instructive and informative by all who are involved in developing either high output or maximum effort competition engines.

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Maitland
New South Wales

power with a sudden rush. Also will you enjoy working at that level of skill and concentration for an extended period of time? You may feel that you have what it takes, but it is worth noting the results of track testing with a number of drivers and engines in two basic levels of tune.

On one occasion we were getting 270–280hp from 2 litres, and that seemed to be the sort of power everyone was aiming for to keep on the pace. The same engine in rally spec was making about 30–35hp less. Then, without the drivers' knowledge, the team's circuit cars were set up with the two different engines: one in circuit spec and one in rally spec. The regular team drivers were both quicker in the car with the more powerful engine, but interestingly both thought the car with the rally engine felt more powerful and they were surprised that they were off the pace by 0.5–0.7 seconds per lap. However, when experienced second-level drivers took their turn behind the wheel the situation changed quite markedly. Of the three drivers involved only one really came to grips with the circuit spec engine. He was generally less than 0.5 slower than the regular drivers, but the other two were erratic, with some laps okay and others over 2 seconds slower. But on switching to the racer with the rally engine, all three were able to pull more consistent and faster lap times than they were able to put down with the circuit spec engine.

On the day that this testing was done the weather was warm and the track surface was dry and in fair condition. On another day with the track damp, or with race traffic and the temperature down a bit, the difference in speed and consistency of the second string drivers as they switched from the circuit spec engine to the rally spec engine would probably have been even more dramatic.

Throughout the book I make regular reference to an engine's state of tune: standard, sports, semi-race and full race. These terms mean virtually nothing (with the possible exception of the first) without some standard against which to measure them.

Basically, I would define a sports modification as one that results in a moderate power improvement without much loss of low-speed tractability. This is the degree of modification that I would recommend for any road-going vehicle.

Semi-race tune would be recommended only for high-speed road or club rally work. The engine would have very little low-speed power and consequently the gearing and vehicle weight would be an important consideration. An engine in this state of tune would almost always require modifications to strengthen the bottom end.

Full race tune is just that — for competition only. An engine in a lesser degree of full race tune would be used in international rallies, quarter-mile dirt speedway and other competitions requiring reasonable mid-range power. A less experienced driver or rider, on the lower-speed road circuits, would be better able to cope with the power characteristics of an engine in this stage of modification rather than be continually battling to keep within the power band of a more highly modified motor.

However, there are so many degrees of full race tune that it is not possible properly to define them. I might add that modifications of this type must be carefully planned to keep the power band compatible with driver ability, circuit layout, race length, engine endurance level and even fuel consumption.

It may appear a trifle laughable, especially in a book on high-performance four-stroke tuning, to include an explanation of four-cycle engine operation. However, I have found that many enthusiasts do not really know what happens inside a four-stroke engine, or for that matter why it is called a four-cycle engine in the first place.

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big power. It is amazing how many people are trapped by this fallacy. Tables 2.1a and 2.1b indicate the valve sizes that you should be aiming for. Valves of this size in an engine in racing tune will yield maximum power at 7,000 to 8,000rpm. Some motors can, because of their over-square design, benefit from the bigger valves listed, and on these maximum power will be gained at 8,500 to 9,000rpm.

Table 2.1a Valve sizes for two-valve motors

Cylinder volume (cc)	Inlet valve diameter (in)	Exhaust valve diameter (in)
125	1.16	1.0
200	1.25–1.31	1.06–1.12
250	1.31–1.37	1.16–1.20
275	1.37–1.45	1.20–1.25
325	1.45–1.53	1.25–1.32
375	1.56–1.60	1.32–1.37
400	1.62–1.68	1.37–1.42
450	1.70–1.75	1.42–1.50
500	1.75–1.85	1.50–1.56
600	2.00	1.65
700	2.10	1.75
800	2.25	1.85
900	2.40	1.93

Table 2.1b Valve sizes for 4-valve motors

Cylinder volume (cc)	Inlet valve diameter (in)	Exhaust valve diameter (in)
250	1.16	1.00
325	1.25	1.06
400	1.31	1.12
450	1.35	1.16
500	1.38	1.20
600	1.50	1.28
700	1.60	1.35
800	1.65	1.40

Using the following formula we can estimate at what speed maximum power will occur for a given inlet valve area:

$$\text{rpm} = \frac{GS \times K \times Va}{CV}$$

GS is the mean gas speed in feet per second. From Table 2.2 you will be able to determine the approximate gas speed by estimating whether the camshaft is standard, sports, semi-race or full race. Keep in mind that many standard factory high-performance road motors employ sports cams.

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Valve sizes in four-valve engines

	Cylinder volume (cc)	Inlet valve (in)	Exhaust valve (in)
BMW M5 3.5	583	1.46	1.26
K1100	275	1.04	.904
Chev ZR-1 5.7	715	1.54	1.39
Weslake heads	625–875	1.5	1.31
Cosworth DFY Formula 1	375	1.44	1.26
DFX Indy	331	1.33	1.15
GAA Gp A	569	1.46	1.26
GAA F5000	569	*1.52	*1.29
BDB rally	425	1.28	1.08
BDG	500	•1.36/1.4†	•1.15/1.2†
BDH	325	1.28	1.0
BDM	400	1.33	1.15
Ducati 850 sports/race	425	1.26/1.34	1.1/1.18
748R	375	1.42	1.18
Ford Cosworth BDA RS1600	400	1.22	1.0
RS 1800	459	1.32	1.15
YB Turbo	500	1.38	1.22
Zetec 2.0	500	*1.34	*1.18
Cobra V8 4.6	575	1.46	1.18
Honda NS750 race	375	1.28	1.12
VF1000R/VF1100	250/275	1.18	1.04
XR500/600	500/589	1.42	1.22
Kawasaki ZZR-1100	263	1.10	.945
ZX-12R	300	1.31	1.11
KLR600	564	1.5	1.3
Lancia Beta turbo rally	356	1.34	1.06
Mercedes 2.3–16	575	1.5	1.3
500 V8 AMG heads	625	1.46	1.26
Nissan SR20	500	1.34	1.18
Opel XE 2.0	500	*1.38	*1.18
Ecotec • 1.8-2.2	450–550	1.26	1.14
Ecotec 1.6/1.8†	400/450	1.22	1.08
Peugeot V10 Formula 1	300	1.57	1.37
Rover K 1.8/1.8VVC	450	1.09/1.24	.95/1.14
Suzuki TL1000	500	*1.57	*1.3
GS 1150	284	1.10	.906
GS 1300	325	1.3	1.08
Triumph 750 Weslake race	375	1.15	1.0
Vauxhall HS2300	575	1.4	1.18
Lotus head	575	*1.44	1.22
VW Golf 1.8	450	1.26	1.10
Weslake speedway	500	1.38	1.13
Yamaha V-Max 1200	300	1.20	1.02
FJ 1100	275	1.14	.984
TT 550/600	550/600	1.42	1.18/1.22

*Non-standard valve size •Early model †Later model

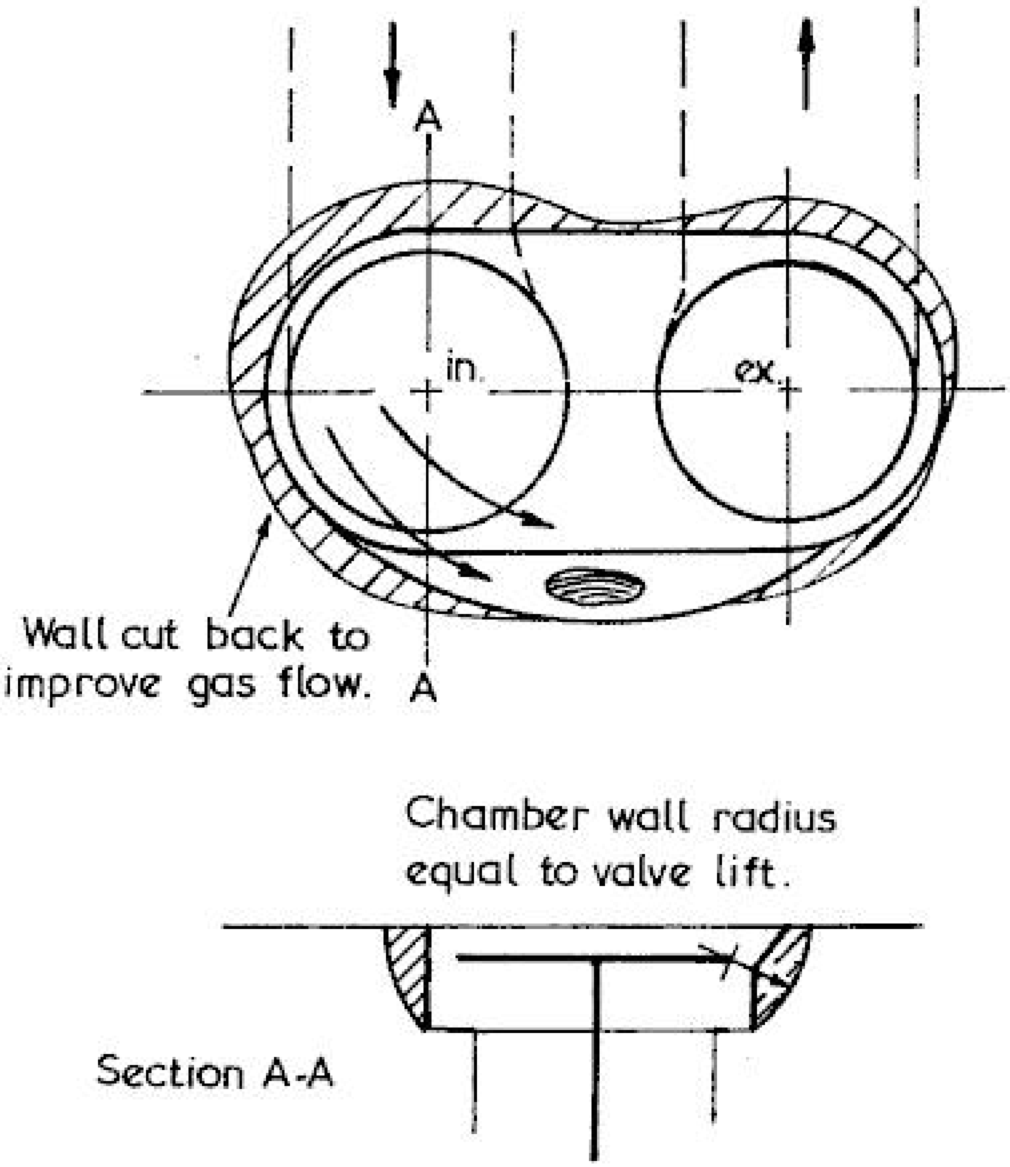


Figure 2.7 Bath-tub chamber modifications.

mixture around the edges of the combustion chamber. This assists in maintaining a steady (not violent) burn rate, and offsets any tendency for high-speed detonation or pre-ignition to occur.

Under certain conditions it is possible for the combustion flame to pre-heat the fuel charge directly in front of the flame to the point of self-ignition. When this flame collides with the spark-ignited combustion flame, explosion-like combustion results (detonation). The quench area normally prevents this by removing excess heat from the outer gases. With the temperature lowered, the end gases do not self-ignite to initiate a dangerous detonation condition.

The quench area also lowers the piston crown temperature by momentarily restricting the combustion flame to just the area of the combustion chamber. This increases piston and ring life, and helps prevent the piston from becoming a hot spot, able to pre-ignite the fuel/air charge.

The exhaust valve requires very little unshrouding at all. I generally work to a figure of 60% of valve lift for the radius between the valve head and chamber wall. It is a mistake to exceed this figure as the exhaust valve flows very well partially shrouded; in fact, it seems to enjoy being shrouded. I well remember an occasion where I was able to pick up 6hp on a VW 1600 by shrouding the exhaust valve a little. Power went up from 163 to 169hp, which represented a 4% gain.

The heart-shaped chamber of the Mini (Figure 2.8) is an easy one to modify. It yields high power due to the inlet port offset producing a good swirl effect. The valves should be unshrouded as with a bath-tub chamber.

A later development of the bath-tub chamber, which also borrows from the

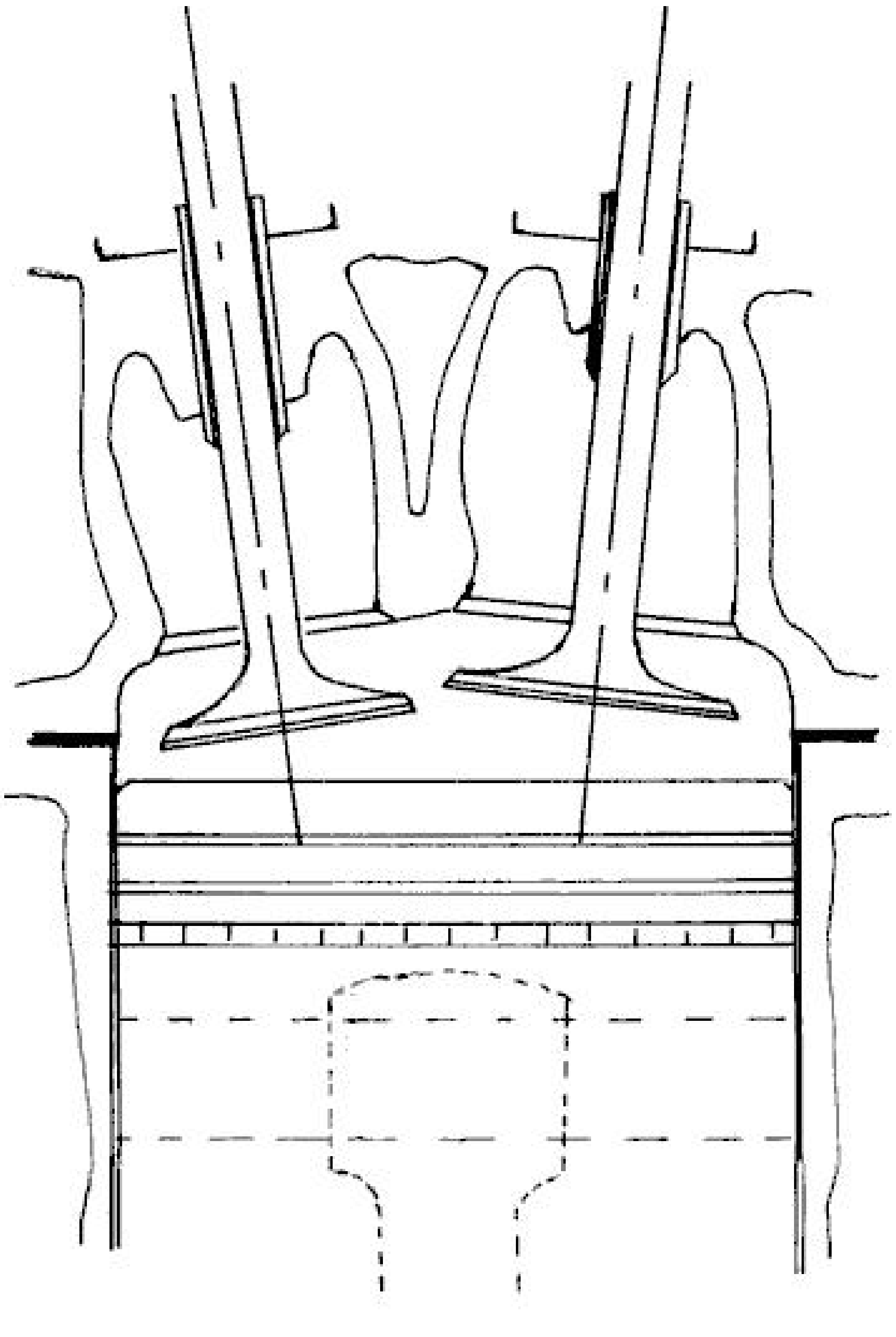
retard mixture homogenisation and combustion flame propagation. A high-top piston obviously masks the spark plug and disrupts flame travel across the combustion chamber. Also of course there is a mechanical penalty; high-top pistons weigh more, so loads on bearings and connecting rods increase. This could mean that heavier, more expensive rods and crank, or a lower rpm limit, are necessary.

This has led to a serious rethink in Detroit. First in 1989 Chevrolet introduced its 18° Bow Tie range of heads for competition engines. These heads feature smaller, shallower combustion chambers, which in themselves promote a better burn and less detonation trouble. This has meant less piston crown protruding into the combustion chamber while allowing the compression ratio to climb to 15:1 on 112 octane race fuel.

Then at the end of 1996 Chev introduced their revised small-block engine, dubbed the Gen III. While still retaining wedge chambers, the valve inclination is further reduced to 15° to produce a more compact combustion chamber and, like the L31 Vortec '906' heads mentioned previously, the combustion chamber is now heart-shaped.

Ford SVO has done something similar with their N351 cast iron competition heads. In these the valves are inclined at only 10° as opposed to the standard 22°. This effectively makes the combustion chamber more compact and means that only a small

Figure 2.10 Big-block Chev head design.



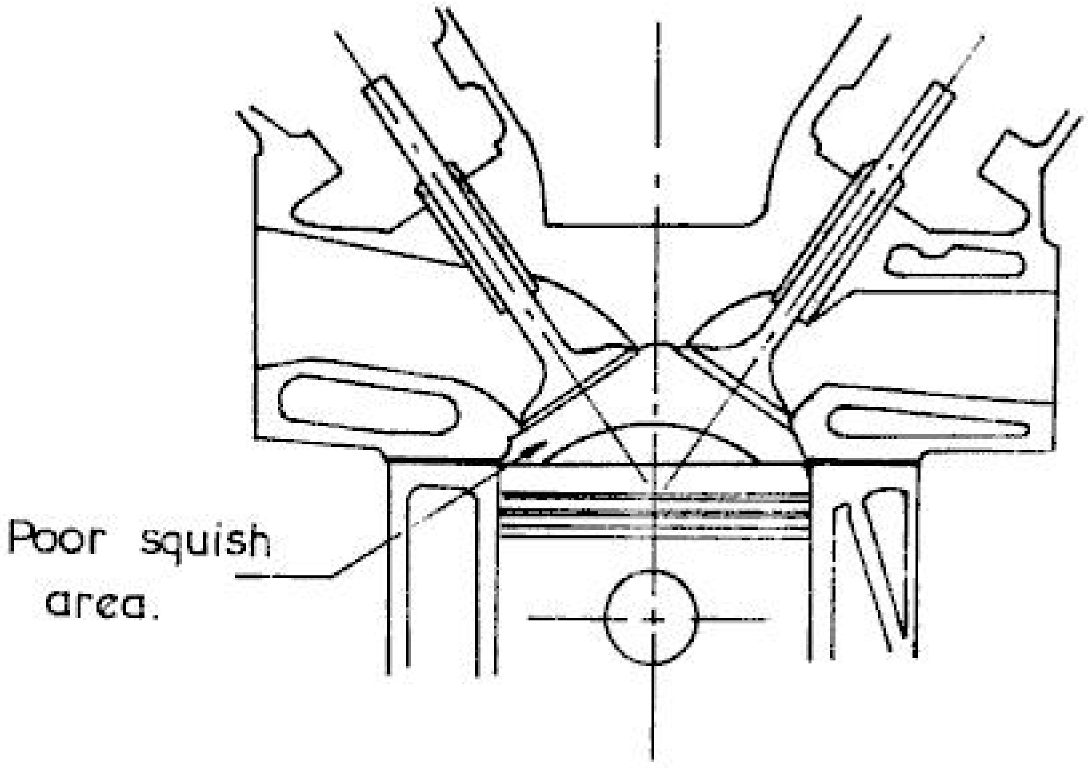


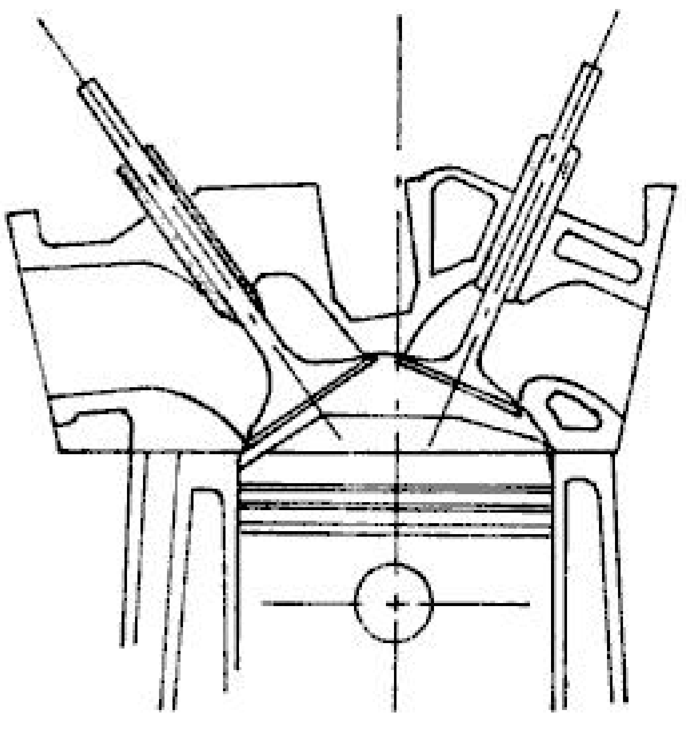
Figure 2.14 Early Jaguar head design.

efficiency. Also, because of the large chamber area, the ignition flame must travel an extreme distance. Consequently two spark plugs were used in racing engines to aid combustion. Even today, after years of development, the Chrysler hemi and the air-cooled flat-six Porsche still work better with two plugs.

Remember our friend squish? Well, he is also lacking with this design. In Figure 2.14 you will notice that some squish does occur due to the radius of the combustion chamber being smaller than that of the piston dome, but this isn't enough to promote good combustion.

Later, the piston dome design was changed to that shown in Figure 2.15. This modification was adopted by both Chrysler and Jaguar. The piston dome in this design is supplemented by a flat section running right round the crown, which comes into close contact with the lower reaches of the combustion chamber. Squish is improved, bringing an improvement in combustion. This has resulted in higher power outputs and a reduction in spark advance.

Figure 2.15 The later Chrysler Hemi has improved squish control.



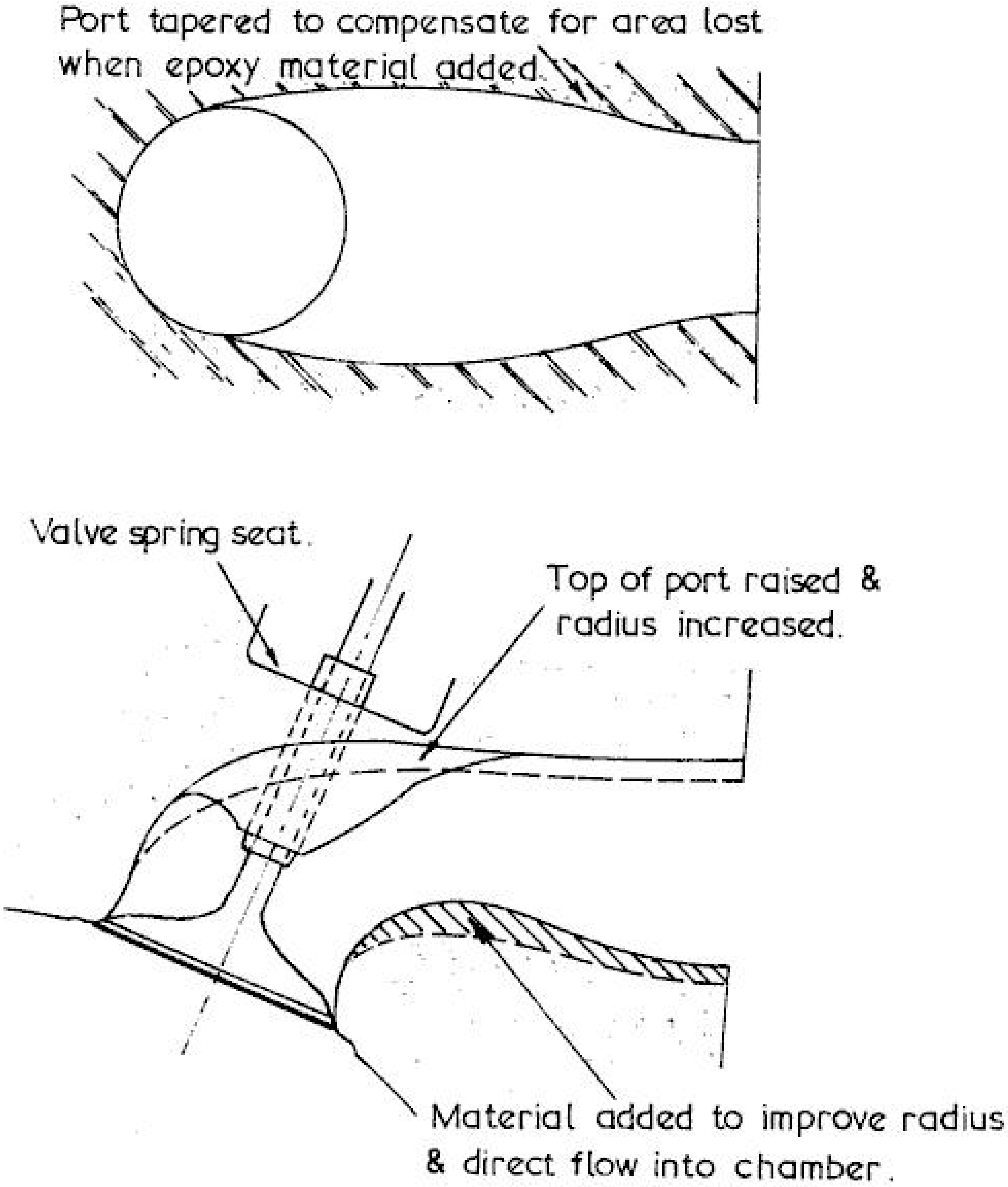


Figure 2.18 Motorcycle inlet port modification.

between the total volume of the cylinder, head gasket and combustion chamber, with the piston at bottom dead centre (BDC), and the volume contained in the space between the piston crown, head gasket and combustion chamber at top dead centre (TDC). Changes in the compression ratio have a considerable effect on power output, because the higher the ratio, the higher the compression pressure at any given engine speed. As is true at all times, you cannot get something for nothing, which applies equally in this instance. An increase in compression ratio brings a corresponding increase in combustion temperature, so will the valves stand it? Bearing loads increase, as does the load on the ignition system, so do not rush in without considering the consequences. As a general rule, a road engine running on 95 to 98 octane petrol will be quite happy on a 9.5–10.5:1 ratio, while racing engines using 100 octane petrol usually run an 11–12.5:1 ratio and up to 13.5:1 on 100/130 Avgas fuel. With methanol, this can be increased to 14:1 or 15:1.

Above a true compression ratio of 14:1 no power is gained. However, if the engine has exceptional anti-detonation characteristics, a theoretical compression ratio of 15:1 may pick up a little power due to the fact that unsupercharged engines seldom,

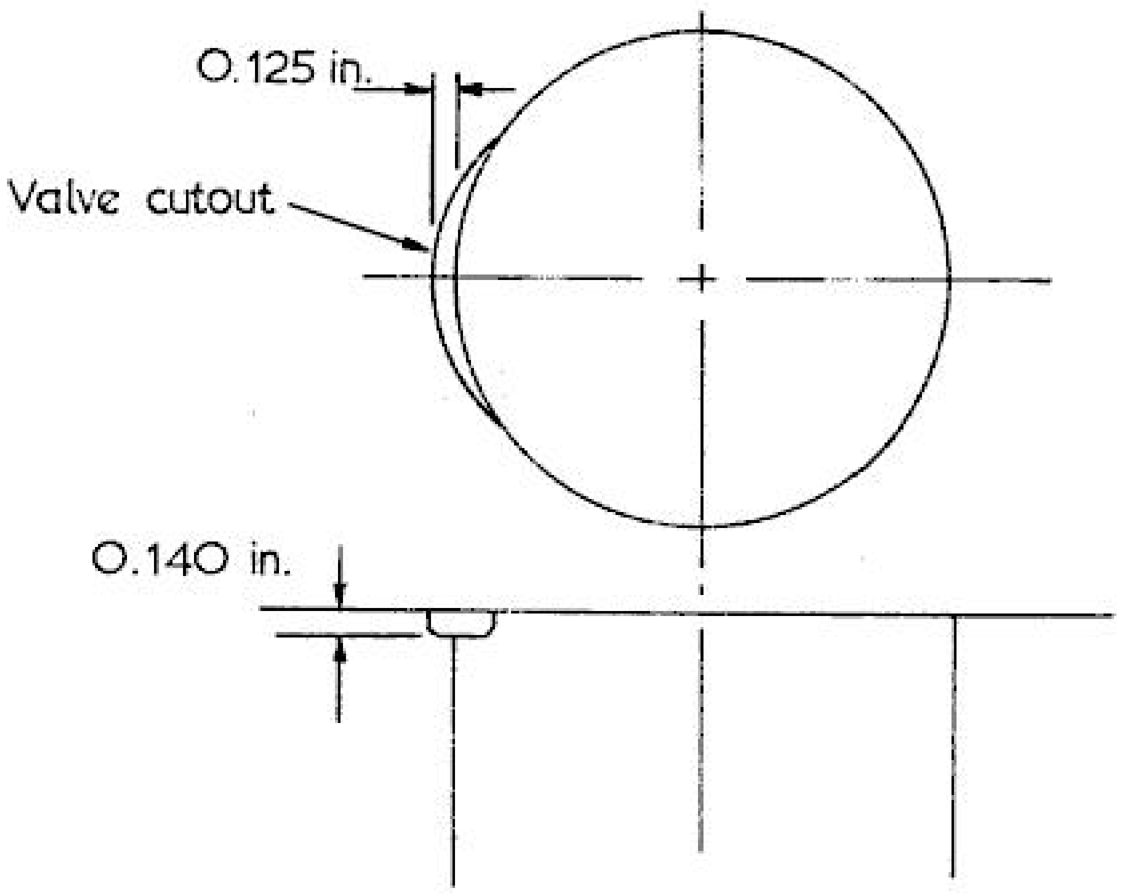


Figure 2.21 Austin Mini exhaust valve cut-out.

springs, retainers and collets to fit, what the valve spring fitted height should be, and what rocker stud modifications are required.

At the same time you should find out if you need to do any grinding of the cylinder block so that your nice big valves do not bang into the top of it. Figure 2.21 illustrates the modification required on the Mini when oversize exhaust valves are fitted. To prevent any damage being done to the piston, rings or bore while this grinding is being done, I would suggest that plenty of grease be applied to the piston crown to seal it in the bore. The grease will trap all the iron dust and prevent it going down the side of the piston.

Only after the block deck has been prepared properly should the cylinder head be fitted. The face of the block needs to be cleaned perfectly, using a flat scraper and knife. Do not under any circumstances use emery paper or wet-and-dry paper as the abrasive particles will undoubtedly end up in the cylinders and on the cam and cam followers, and compressed air will not budge it. If the block has dowels or head studs still in place, be very, very careful to remove any traces of old gasket or rust from around the base of these, using a knife.

The head gasket has the task of sealing the head to the block, and has to be able to withstand a pressure of up to 1,800psi in supercharged racing engines, so choose carefully. On a high-performance motor, copper asbestos gaskets are definitely out and so too are stainless steel examples. About the best that you can buy for British engines is a steel/copper/asbestos gasket. This type has a mild steel face and sealing lip on one side, copper sheet on the other face, and asbestos in between. With care, this type of gasket can be re-used a number of times. For American engines you should use either a heavy duty Fel-Pro composition gasket or a mild steel gasket. Do not use the latter if the head or block is aluminium as these distort more and the gasket will not be able to effect a good seal. Also be sure to fit steel gaskets the correct way up, that is with the channel rolled into them facing up as if to hold water.

On all copper/steel/asbestos gaskets I use Rolls-Royce Hylomar sealant. For

Nearly all carburettors employ a fuel inlet system, an idle system, a main running system, and also an acceleration-pump system and a power system.

The inlet system consists of the fuel bowl, the float, and the needle and seat.

The fuel passing to the other metering systems is stored in the fuel bowl and is maintained at the correct level by the float and the needle and seat. If the fuel is not at the correct level in the fuel bowl, the fuel metering systems will not be able to mix the fuel and air in the correct proportions, particularly when accelerating, cornering and stopping.

A high fuel level will cause high fuel consumption and erratic running. Due to fuel spill-over through the carburettor discharge nozzle and/or vent during cornering or braking, it could cause the engine to falter or stop. The high level may be the result of an incorrectly adjusted float, or a needle that is not seating properly and shutting off the fuel supply when the float reaches the correct level. This may be due to excessive wear of the needle and/or seat, or it may be caused by a weak bumper spring (Holley carburettors). High fuel pressure will also raise the fuel level, each 1psi increase in fuel pressure raising it by about 0.020in.

A low fuel level causes flat spots because of lean-out in turns and when accelerating. Even more serious is the possibility of a full power lean-out due to reduced fuel flow capacity, resulting in melted pistons. The low fuel level may be due to an improperly adjusted float, low fuel pressure, an excessively strong bumper spring (Holley carbs), or a needle and seat too small to flow sufficient fuel to keep the fuel bowl full.

The fuel bowl is always vented so that the fuel is being mixed according to the outside air pressure. Once the fuel passes through the needle and seat it is no longer under pressure. Any fuel vapour is released through the vent, so at all times the metering systems respond to the prevailing atmospheric conditions.

The float is hinged in such a way that it operates the opening and closing of the fuel inlet valve (needle and seat). As the fuel drops, the float drops and opens the valve, allowing fuel to enter the bowl. When the engine is running with a constant load, the float moves the needle to a position where it restricts fuel flow, allowing in only enough fuel to replace that being used.

The float may be made of brass stampings soldered together into an airtight assembly, or of a closed cellular material. Brass floats are resistant to attack from all types of fuel, except nitromethane. Generally, the cellular floats are not damaged by most of the common fuels, but it is always wise to check with the carburettor manufacturer if you are using a fuel other than petrol or methanol.

The needle and seat fuel inlet valve controls the flow of fuel into the bowl. The seat is usually steel and the needle may be steel or steel with a Viton coating on the tip. The latter provides good sealing, but it should not be used with alcohol or nitro fuels.

The needle and seat are usually available in a number of sizes to give the required rate of fuel flow into the bowl. The seat size is selected to allow reasonably quick filling of the bowl so as to be able to meet the demands of wide-open throttle and high rpm operation. A seat that is too large is a definite hindrance, as it may give rise to flooding. For this reason use an inlet assembly only marginally larger than the fuel flow requirement of the engine.

How much fuel does your engine need? Remember we said that the best power is produced with a fuel-air ratio of 1 pound of fuel to every 12½ pounds of air (only if

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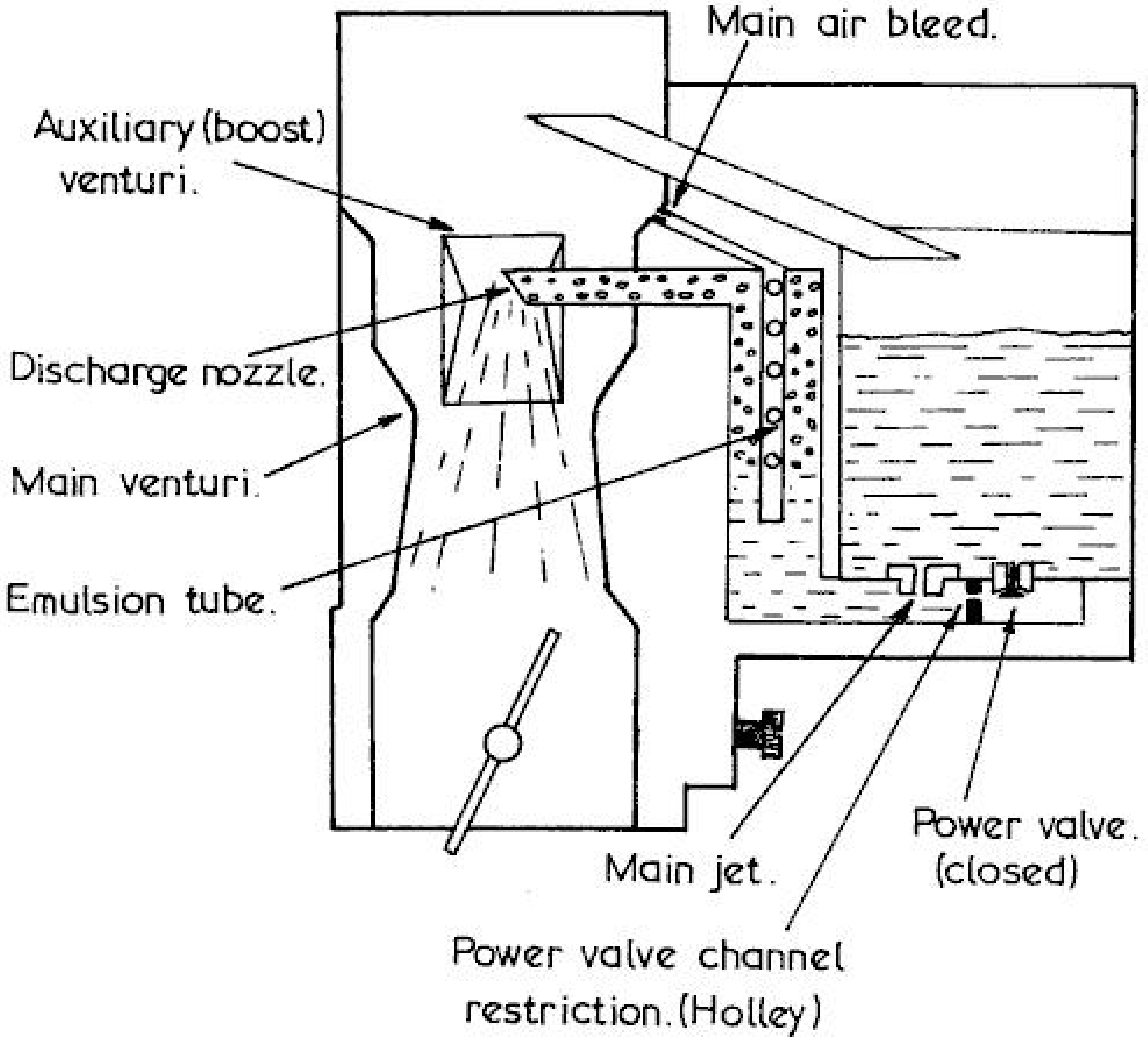

Figure 3.3 Main and power system operation.

ago.

The venturi necks down the inrushing air, then allows it to widen out to the throttle bore. To get through the venturi, the air must speed up, thus reducing the pressure inside the venturi to below atmospheric pressure. This pressure differential allows the main system to discharge fuel, and is commonly referred to as the 'signal' of the main metering system. No fuel issues from the discharge nozzle until the air flow through the venturi produces a pressure drop or signal sufficiently strong for the atmospheric pressure, acting on the fuel in the fuel bowl, to push the fuel up through the main jet to the discharge nozzle.

Pressure drop (or vacuum) within the venturi varies with the engine speed and throttle opening. A wide-open throttle and peak rpm will give the highest air flow, and consequently the highest pressure difference between the fuel bowl and the discharge nozzle. This in turn gives the highest fuel flow into the engine.

To compensate for various engine displacements, carburettors with a variety of venturi diameters are available to create the necessary pressure drop to bring the main fuel circuit into operation. A small venturi will provide a higher pressure difference at any given rpm and throttle opening than a large-diameter venturi. This is a very important aspect of carburation, which partly explains why the biggest is seldom the best. If the signal being applied by the venturi is too weak (due to the venturi being too large), this could delay fuel discharge in the main system, causing a flat spot. If you must err when buying a carburettor, err on the small side.

The auxiliary venturi acts as a signal amplifier for the main venturi, allowing for

US gallons. If you live outside the US you will run into trouble if you calculate your fuel flow to be, say, 70gph and you fit a 70gph American pump. One US gallon is 0.8 of an Imperial gallon, so the American pump will actually flow 56 Imperial gph. (The above rule of thumb calculates the fuel flow requirement in Imperial gallons per hour when working from the maximum horsepower.)

Most high-flow American fuel pumps have a very high delivery pressure, which may cause English and European carburettors to flood. Holley carburettors are designed to operate at an idle speed pressure of 6–7psi, and 4.5psi at maximum speed. Weber carburettors should not have a delivery pressure (at the carburettor) of more than 4–4½psi at idle, and the pressure at maximum speed should not be less than 3psi.

To regulate the pressure, you will have to use an in-line pressure regulator or a by-pass line. Holley make a regulator for use with their high-pressure pumps, which pump at up to 15psi unregulated. The regulator must be fitted close to the carburettor, then adjusted according to the fuel pressure gauge reading at idle.

Some racers prefer to use a by-pass line from the pump outlet back to the tank, to reduce the pressure. This system will work very well, but a lot of time can be spent finding what size of restriction plug should be fitted in the by-pass line to get the required fuel pressure. I would recommend that you use a ¼in line and start your testing using a restrictor with a 1/16in hole.

The front-mounted fuel pump is acceptable in most instances for engines in up to medium semi-race tune. Above this degree of modification an electric pump mounted near the fuel tank should be used.

The main weakness of using a front-mounted pump is that it aggravates vapour lock. A high-performance engine requires a lot of fuel so the line from the pump back to the tank will always be subjected to suction or a vacuum. This means that the fuel in the pipe is going to boil at a much lower temperature than it would if at normal atmospheric pressure. The only way around this is to use a rear-mounted electric pump.

In large displacement racing machines it is at times necessary to use two or three electric pumps. These must be connected in parallel, so that each has an inlet line running to the fuel tank. The outlet lines may be left separate until they reach the front of the car, or they may be connected to a single large-bore fuel line.

When installing an electric pump I recommend that a Holley safety switch be included in the electrical circuit, so that the pump will not work unless there is oil pressure. This not only ensures that the engine will not be flooded when it is switched off (a simple isolator switch will also do this), but more importantly, in a crash gallons of fuel could otherwise be pumped over everything before the pump was switched off, if an ordinary switch was used. With the ever-present risk of fire, this would be extremely dangerous.

The fuel line must be protected from possible mechanical damage for the same reason. Flying stones or abrasions between rubbing parts could puncture the line and allow fuel spillage. To avoid this, the line must be carefully routed, and sections exposed to stone damage must be shielded with suitable covering.

The line may also fracture because of vibration. To overcome this, a flexible section of line of sufficient length must be used to connect the fuel line to the engine and also the fuel tank. If an electric pump is used, flexible line must be used on the inlet and outlet as these pumps are subject to considerable vibration.

being used. Some use other more volatile fuels blended with the methanol to help overcome this problem; usually 5% acetone or a maximum of 3% ether is used. Starting aerosols containing ether should not be used due to the possibility of engine damage being caused by detonation. Personally I feel that the best method is to spray either petrol or straight acetone down the throat of the carburettor. Do not attempt to do this while the engine is being cranked over; if it backfired you could be badly burned.

Is the ignition system up to the job? Many alky burners use magnetos for a very good reason. Not only does the ignition system have to cope with much higher compression pressures, it may also be called upon to fire wet plugs due to the very rich mixtures that are used.

Methanol burns much more slowly than petrol, so it is necessary to advance the ignition accordingly. With some motors 6° more total advance is enough, while others may require 15°. As a guide you can reckon on requiring 36° advance if you run 30° burning petrol, or if you run 40° on petrol you will possibly need close on 50° with alky.

Nitromethane is burned in the most powerful drag machines. Usually 80–90% nitro and 10–20% methanol is the ratio at which fuel is blended for this purpose.

On the speedway scene nitro is used in smaller percentages (usually 10–20%) as a power booster. Methanol is always the base fuel, and acetone may also be added.

Nitromethane is a very special fuel that will lift the power output of an engine quite considerably (70%). This is due to nitro containing approximately 53% by weight oxygen. In itself, nitromethane is a very poor fuel, but because it contains so much oxygen it permits the induction of huge quantities of fuel into the engine for conversion into heat energy.

To deter detonation or other engine damage, it is always necessary to reduce the compression ratio when nitro is used. If you find that your engine is reliable running a 15:1 compression ratio with methanol, you could use up to 20% nitro by reducing this to a 12:1 ratio. With 60% nitro, the compression ratio would have to be further lowered, to around 9:1, or 7.5:1 if 80–90% nitro is used.

At all times the fuel/air mixture must be very rich. With an 80–90% blend of nitro it may be as rich as two parts fuel to one part air, or as lean as one part fuel to two

Table 3.9 Fuel jet size for nitromethane

% nitro in methanol *(by volume)*	***Jet diameter increase over straight methanol**
10	1.12
20	1.22
30	1.32
40	1.41
50	1.5
60	1.58
70	1.66
80	1.73
90	1.8

*Multiply jet size by the appropriate number

When propylene oxide or nitropropane are blended with methanol in the above percentages they provide a power boost similar to that when they are added to leaded race fuel. However, if more than about 3% acetone is present in the methanol they must not be used. Many fuel companies blend in 2–3% to improve methanol's ability to be blended with other fuel compounds. Actually up to 10% acetone will improve the combustion rate of methanol, improve cold weather starting, and reduce a tendency to pre-ignite when lean mixtures are used. Up to 10% water is also an effective lean mixture detonation suppressant.

In the past a fairly reliable method of increasing the octane rating of petrol was to add up to 33% toluol (toluene, methyl benzine). This percentage would raise the octane rating of leaded fuel (0.2gm lead/litre) about 6 numbers Research and 2.5 numbers Motor respectively. However, as lead levels have decreased, government regulations permitting, petrol refiners have substituted high-octane hydrocarbons to bring the octane numbers back up, so a reliable octane increase cannot be guaranteed by their addition, particularly to higher-octane unleaded, and to a lesser degree high-octane leaded. A guide as to whether fuels such as toluol, triptane, benzol (benzene), xylene, etc, have been added by the fuel company is to check out the specific gravity. If the SG is high and there is no government regulation limiting these products to a maximum of 5% (they are reported to be cancer-causing), the petrol probably contains up to 20% of these products either singularly or in combination.

However, if the government limits their use to a maximum of 5%, then with the exception of benzol and triptane all will provide a good octane boost of about 1 Motor number for every 10% added up to a maximum of around 25%. Additionally, in distance racing, by virtue of their high SGs, they significantly reduce fuel consumption and thus the number of pit stops required.

Another very effective octane booster, MMT (methyl cyclopentadienyl manganese tricarbonyl), is the base product in both 104+ and 104+ Super octane boosters. MMT works best in unleaded and low-lead fuels. Whereas a can of this stuff, which at normal concentration will treat 83 litres of petrol, raises the Research number of unleaded by about 3–4 and 4–6 respectively for 104+ and 104+ Super, with leaded (0.2gm lead/litre) this decreases to around 0.5–1 and 1–2 octane increase. When mixed with racing unleaded the octane increase will be similar to that achieved when it is blended with leaded fuel.

Weber carburettors are known the world over as about the best that money can buy. However, many people do not realise that there are Webers and Webers. Some are simply metering devices for use on baby Fiats; others, such as the DCOE and IDA series, are racing carburettors that can be tuned to work very well, even on mildly modified street engines.

Many people feel that the Weber is difficult to tune; they never seem to be able to get it to work correctly. I would say that the Weber is one of the very easiest of carburettors to tune, and that it holds its tune even when subjected to severe banging on a rally car.

The Weber DCOE is a sidedraught unit available with throttle bore diameters of 40, 42, 45, 48 and 50mm. Because of the large range of venturis (commonly called 'chokes') available, these five basic carburettors can be tuned to suit any engine.

The downdraught Weber IDA is available in sizes of 40, 44, 46 and 48mm. It

The size of the pump jet and the pump bleed jet (or exhaust jet), and the length of the pump rod all affect the amount of fuel supplied during acceleration. The size of the pump jet alone determines the fuel metering when the pump circuit serves as a high-speed power circuit. Therefore the pump jet size is selected to supply the correct fuel/air mixture for high-speed operation.

Once the correct pump jet has been chosen, you have to determine if the mixture is too rich or lean during acceleration. If too much fuel is supplied, it may be necessary to use an open pump bleed jet, which is situated in the bottom of the fuel bowl, under the float(s). Usually a closed jet (ie one without a bleed hole) is used in semi-race and racing motors. However, if the mixture is too rich during acceleration, a pump bleed jet will be required. These are available with a bleed hole from 0.35 to 1.5mm. If a bleed jet is required, usually a 40, 45 or 50 will be the correct size. To remove or replace this jet you will need a special screwdriver with a 'screw-grip' attachment.

The length of the pump rod governs the amount of fuel in the pump well; the longer the rod, the bigger the shot of fuel available. Rods of varying lengths are available for the DCOE model carburettor, but with the IDA the pump stroke can be shortened by the use of a collar.

The promptness of fuel delivery is controlled partly by the bleed jet and partly by the strength of the pump spring. A closed bleed jet and a strong spring gives a quick shot of fuel of short duration. If a weaker spring is used, there will still be a quick initial delivery of fuel, but the duration of the delivery will be longer. The use of an open bleed jet delays the delivery of the fuel, and reduces the amount delivered.

Seldom is it necessary to change either the length of the pump rod or the strength of the pump spring. However, at times I have found it advantageous to use a strong spring and a 59.5mm rod when a single 45 DCOE is used on the 1300 Mini Cooper 'S' and 1800 MG 'B' engines.

Both the DCOE and IDA model carburettors have an idle jet assembly that meters fuel and air into the idle circuit. When the correct jet has been chosen, the mixture adjustment screw should be 1/4 to 1 1/4 turns open to obtain the correct idle mixture.

In DCOE carburettors the idle jet has a fuel hole and an air bleed hole. The fuel hole size is the first number stamped on the jet, eg if the jet is a 45 F9, the fuel hole is 0.45mm; F9 is a code referring to the air bleed hole size. Table 3.14 sets out the 'F' code, from rich to lean. Some jets have two air bleed holes, but this has been taken into consideration when working out the table.

All IDA idle jets are coded F10. The F10 jet does not have an air bleed hole; instead air correction is handled by the idle jet holder. The 1366cc Mini, for example, uses a 60 F10 idle jet and a 120 jet holder. This indicates that the jet holder has a 1.20mm air bleed. A 100 or 120 jet holder is used in the majority of applications. A larger air bleed hole leans the idle mixture.

To determine the approximately correct idle jet refer to Table 3.15, which sets out the sizes of the fuel metering holes. If, for example, the cylinder capacity is 400cc, you will require a 50 F8 or 50 F9 jet with which to begin testing. I have arbitrarily selected an F8 or F9 air bleed hole in this instance as either size is correct in 80% of cases; the other 20% use an F2 or F6 air bleed.

If you were using an IDA carburettor you would select a 50 F10 idle jet in the above example, and you would use either a 100 or 120 jet holder.

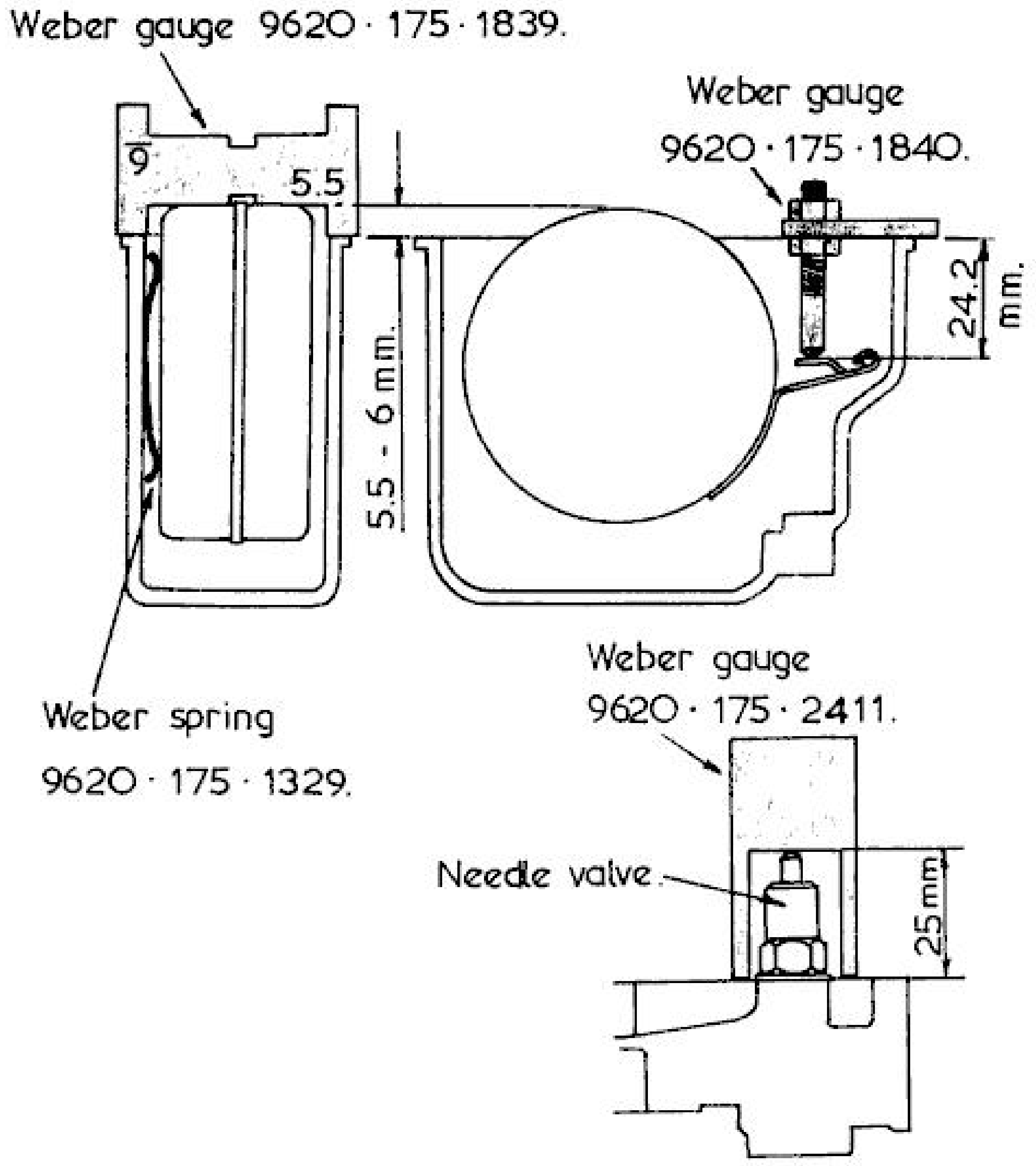

Figure 3.12 Weber IDA float levelling.

level is 12.5–13mm. On Lamborgini Miura cars equipped with IDL carburettors, float level gauge No 9620.175.3071 is used, and in this case the float level is 14–14.5mm. All of these three-barrel carburettors have a needle-ball-to-carburettor-top dimension of 18mm.

There are just a few points to keep in mind when Weber carburettors are fitted. First, I would suggest that you obtain a copy of the Weber Technical Introduction 2nd edition (or later) and follow very carefully their installation instructions. Pay careful attention to what they have to say about throttle linkage arrangements so that all the butterflies open together.

DCOE carburettors must never be mounted solidly, but must always have a neoprene insulator block or a light alloy plate with an 'O' ring in both faces fitted between the carburettor and the manifold. This is necessary to reduce carburettor vibration, which causes fuel frothing, flooding and inaccurate metering.

When tightening the carburettor mounting bolts, ensure that they are tensioned just enough to effect a good seal, but not enough to squash the 'O' rings or insulator block. Self-locking nuts and, if possible, light double-wound spring washers should be used, as fitted on the Twin Cam Ford Escort; these are designed to be tightened until there is a gap of 0.040in between the coils.

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choose a needle for an engine that is similar to yours. After that, it is a matter of testing to find at what point the needle is rich or lean. Then you will have to consult the complete SU needle tables and find a needle that is richer or leaner at the point where you want it to be.

Table 3.19 SU tuning specification

Engine		Displacement (cc)	Tune	Carb	Needle	Spring
Austin		997	sports	2 x 1¼in	GZ	Red
		998	sports	2 x 1¼in	GY	Blue
		970	sports	2 x 1¼in	AN	Red
		1070	sports	2 x 1¼in	H6	Red
		1275	sports	2 x 1¼in	M	Red
		970	full-race	2 x 1½in	CP4	Blue
		1070	full-race	2 x 1½in	MME	Blue
		1275	full-race	2 x 1½in	BG	Blue
		1098	sports	2 x 1½in	AM	Blue
		998	semi-race	2 x 1¼in	M	Blue
Austin Healey		2912	full-race	3 x 2in	UH	Blue/Black
		2912	sports	3 x 2in	UH	Red/Green
		2912	sports	3 x 1¾in	BC	Green
		2912	sports	2 x 1¾in	CV	Yellow
Ford		997	sports	2 x 1¼in	A5	Blue
		1198	sports	2 x 1¼in	H6	Red
		1500	sports	2 x 1½in	CZ	Red
		2553	sports	3 x 1½in	3	Red
		2553	sports	3 x 1¼in	ES	Red
		2553	sports	2 x 1½in	7	Yellow
		997	full-race	2 x 1½in	AM	Blue
Hillman	ohc	875	sports	2 x 1¼in	H4	Blue
		1600	sports	2 x 1½in	QA	Red
Jaguar	T/C	3441	sports	2 x 1¾in	TL	Red
	T/C	3781	sports	2 x 1¾in	TU	Red
	T/C	3781	sports	3 x 2in	UM	Blue/Black
	T/C	4235	sports	3 x 2in	UM	Blue/Black
	T/C	3441	sports	3 x 2in	UE	Blue/Black
MG	T/C	1588	sports	2 x 1¾in	OA6	Red
		1800	sports	2 x 1½in	MB	Red
		1800	full-race	2 x 2in	UVD	Blue/Black
		1098	sports	2 x 1¼in	AN	Blue
		1800	semi-race	2 x 1¾in	KP	Red
Triumph		1147	sports	2 x 1¼in	MO	Red
		1147	full-race	2 x 1½in	DB	Blue

When going from a weak needle to a richer one, it is better to try one about 0.002 thinner at a time, but when changing from a rich needle to a weaker one try a needle 0.001 thicker, unless there are signs of excessive richness.

Table 3.22 Holley carburettor recommendations

Engine	Cubic in	Tune	Manifold type	Carb No	Size CFM
Buick	455	sports	Edelbrock B-4BQJ	R-6979	600
		semi-race	as above	R-4780*	800
	231 V6	semi-race	Offenhauser Dual Port	R-1849	550
Chevrolet	200-229 V6	sports	Holley Street Dominator	O-9694	450
	283-305	sports	Edelbrock Performer	R-6979	600
		semi-race	as above	R-4776*	600
	327-350	sports	Edelbrock Performer or Torker	R-6979	600
		semi-race	as above	R-4778*	700
		semi-race	Edelbrock Victor Jr	R-4778*	700
		full-race	Edelbrock Victor 4 + 4	R-4780*	800
		sports	Holley Street Dominator	R-1850	600
	396-427	sports	Edelbrock Torker	R-6979	600
		semi-race	as above	R-4781*	850
		semi-race	Edelbrock Victor Jr 2R	O-4781	850
		full-race	Edelbrock Victor 2R	R-4781*	850
				or R-4575*	1050
Chrysler	340-360	sports	Edelbrock Torker or Performer	R-7009	600
		semi-race	as above	R-3310	780
		full-race	Holley Strip Dominator	R-4778*	700
	413-440	sports	Edelbrock Torker	R-7009	600
		semi-race	as above	R-4779*	750
		full-race	as above	R-4780*	800
Ford	170 V6	sports	Offenhauser Dual Port	R-6299	390
	289-302W	sports	Holley Street Dominator	R-1850	600
		semi-race	as above	R-4777*	650
	351W	sports	Holley Street Dominator	R-1850	600
		semi-race	as above	R-4777*	650
	351C	sports	Edelbrock Torker	R-7010	780
		semi-race	as above	R-6709*	750
		full-race	Holley Strip Dominator	R-4781*	850
	390-428	sports	Holley Street Dominator	R-6919	600
		semi-race	as above	R-3310	780
	429-460	semi-race	Edelbrock Torker	O-3310	780
		full race	as above	O-4780	800
Oldsmobile	400-455	sports	Edelbrock Torker	R-3310	780
Pontiac	400-455	sports	Edelbrock Torker	R-3310	780
		semi-race	as above	R-4780*	800

*Indicates double-pumper carburettor.

A late development by Holley has seen the introduction of a new close-limit series of jets. These were developed primarily for pollution control carburettors, but they are very useful for fine-tuning performance engines. These jets also have the prefix 122 followed by the jet size number, but following the jet number is a suffix, indicating the jets' flow variation from standard. For example, a 662 jet is a size 66 jet

valve that opens at a manifold vacuum 2 inches lower than the primary valve. Therefore if the primary valve is an 85, a 65 will be used in the secondary. There are exceptions to this general rule. Holley calibrate a small number of their carburettors with the same number primary and secondary valve or even with a primary valve of a lower number than that of the secondary valve.

When it comes to tuning the accelerator pump on the Holley there are a number of factors to consider. First, Holley offer two different pumps. The standard pump is a 3cc (or 30cc per 10 shots) unit. They also have available an optional 5cc (50cc per 10 shots) pump, which is fitted as standard on the secondaries of all their double-pumper mechanical secondary carburettors. The 5cc pump should be used in all semi and full race applications.

Two other components, the pump cam and the discharge nozzle, actually regulate the pump delivery. The total lift of the cam controls the pump stroke, and the profile of the cam affects the phasing of the pump.

The pump cam can be attached in two positions. In the more usual No 2 position it provides a greater initial delivery of fuel and less final volume; the No 1 position gives a moderate initial delivery and more final volume.

The shape of the pump cam is of little importance in drag racing providing that a cam giving a sufficiently long pump stroke is used. However, on the road or racing circuit the shape of the cam has a great effect on throttle responsiveness. A sharp-nose cam gives a quick pump action while a cam with a more gentle shape delivers a slower action.

Holley pump cams are colour coded. Table 3.25 indicates which cam supplies the most fuel (rich cam) and which supplies the least, in both the No 1 and No 2 positions. In most instances the richest cam supplies about double the volume of fuel of the leanest cam.

Table 3.25 Holley accelerator pump cams

	No 2 position	**No 1 position**
↑	black	white
	white	blue
leaner	red	red
	blue	orange
richer	orange	black
	green	green
↓	pink	pink
		brown

Note: this chart considers only the volume of fuel delivered, not delivery promptness or duration.

The accelerator pump discharges through the discharge nozzle (shooter), which is available in a number of sizes. The number stamped on the nozzle indicates the bore size in thousandths of an inch, ie a 28 nozzle has a 0.028in discharge hole.

A small discharge nozzle lengthens the delivery duration, while a large nozzle provides a larger initial volume of fuel. Therefore a car fitted with a large motor in relation to its weight and a numerically large axle ratio will need a large discharge nozzle.

When it comes to tuning, find which nozzle gives the crispest throttle response, then try the different cams to see if the response can be improved. If a better cam is found, go through the discharge nozzles a second time to be sure that you have found the combination that will give the best performance.

There are a couple of important points to keep an eye on when working with the Holley accelerator pump. First, the pump over-ride spring must never be adjusted so that it is coil-bound. The spring must always be compressible to avoid damage to the pump or pump diaphragm. Also, be sure to check that there is no clearance between the pump actuating lever and the pump cam. Just changing the idle speed can move the cam away from the lever, which will delay the discharge of fuel from the pump. When you re-adjust the pump lever adjusting screw to make contact with the cam, be sure to check that at wide-open throttle the diaphragm lever can travel an additional 0.015–0.020in by inserting a feeler gauge between the lever and the adjusting screw.

Holleys with vacuum-operated secondary barrels should not be changed over to mechanical operation. Some people feel that this must improve performance because all of the racing Holleys have mechanically opened secondary throttles, but remember that these are double-pumper carburettors and the secondary pump is able to prevent a lean condition when the secondaries are blasted open.

Other people like the 'kick in the pants' feel that you usually get when you change from vacuum control to mechanical. What you are actually feeling is a flat spot followed by a surge of power as the fuel supply catches up with the air flow into the motor.

To allow you to 'tune in' the secondary opening and the rate of opening, Holley provide a selection of diaphragm springs. A light spring will allow the secondaries to open sooner and more quickly than a heavy spring. A light car with a large powerful motor will use a lighter spring than a heavier car with the same motor and rear axle ratio. Table 3.26 indicates the range of springs available. Most Holleys have a green, purple or red spring fitted at the factory.

Table 3.26 Holley vacuum secondary springs

↑	x	Black
	x	Brown
	x	Plain (unpainted)
		Orange
stronger		Green
	x	Purple
softer		Pink
		Red
	x	Yellow
	x	Yellow (short spring)
↓	x	White

Note: springs marked 'x' are supplied in Holley spring kit No 20–13.

The way to find which spring will give the best performance is to time your acceleration from about 3,000–3,500rpm to maximum engine speed. Obviously the optimum spring is the one that shows the quickest time. To reduce the number of variables to a minimum, carry out the test in top gear and over the same stretch of road.

As mentioned earlier, there is no other modification that you should do to 'improve' the secondary throttle operation. Change the springs by all means, but leave everything else alone.

At times, vacuum-operated secondary throttles can be slow or sticky in operation, due to the accumulation of gum and carbon on the throttle shaft. Regularly, and before you attempt any tuning, you must hold the primary wide open and manually open the secondaries. No stiffness should be encountered and the secondaries should close smoothly, unassisted.

If, after you have manually opened and closed the secondaries several times, resistance is still present, you can be reasonably certain that the binding is due to incorrect or uneven tightening of the carburettor base nuts. This can be a problem when a phenolic heat insulator is used between the carburettor and the manifold. The insulator is necessary to isolate engine heat from the carburettor, but take care to tighten each nut a little at a time so that the carb base tightens down evenly, without distortion. The use of thick or multiple-base gaskets is to be avoided as this can lead to base distortion and shaft binding.

The idle metering system on Holleys is non-adjustable, except for the mixture screw. There are pressed-in brass air bleeds in the air horn and fuel flow restrictors in the metering blocks. The only way around the problem is drilling the air bleeds (to lean the mixture) or the idle feed restriction (to richen the mixture). This is definitely not a job for the average enthusiast.

In the majority of road applications no changes to the idle system metering will be necessary, but racing engines will require some change. If you do not have the patience or skill to attempt this very fine work, find someone who can do the modifications, or be prepared to spend a lot of money on ruined metering blocks.

If you find that the engine will not idle, first ensure that there is not something else wrong. Air leaks, loose screws, incorrect float or fuel level, etc, will all cause you some problem and distort the picture. Only after you have thoroughly checked everything should you modify the carburettor in any way.

Keep an accurate and complete record of every move you make from this point. Remove the carburettor from the manifold and, with the throttle lever held against the stop (first wind the screw back to the factory setting), measure the throttle-plate-to-throttle-bore clearance in both primary bores, using a feeler gauge.

Refit the carburettor and start the engine. Note how many turns you have to give the idle speed screw to keep the engine running, then attempt to adjust the mixture screws to improve the idle. (It is important that you first lightly seat both screws, then turn them out an equal amount.) If turning both screws an equal amount does not seem to improve the idle, record that fact.

If you haven't already checked the idle vacuum and fitted a power valve that will stay closed at idle, do so now, and check the idle after the change.

Remove the carburettor if there is little or no improvement and turn it upside down. Then measure how much of the transfer slot is visible above the throttle plate. If there is more than 0.040in visible, drill a $^1/_{16}$in hole in each throttle plate (primary side only) about midway between the throttle shaft and the edge of the throttle plate. (Drill the hole on the same side of the plate as the transfer slot.)

Some Holleys already have throttle plate holes from the factory so in this instance it will be necessary to enlarge the holes by the equivalent of a 1/16in hole in area; ie if the standard hole is 1/16, increase the hole size to 0.088in (or 3/32in closest equivalent).

Before refitting the carburettor, adjust the idle speed screw to obtain the factory-set clearance between the throttle plate and throttle bore (this is the first measurement you recorded).

Refit the carburettor and start the engine. If after adjusting the mixture the idle speed is right, the holes are of the correct size. If it is too slow, larger holes are required, or if too fast, solder over the holes and redrill them a smaller size.

When you are sure that the throttle plate holes are the correct size, check how much change occurs to the idle speed by turning out the mixture screws to richen the mixture. (Note that on some Holleys you turn the screw *in* to richen the mixture.) If the engine speed drops and the engine runs rough, the idle feed restriction in the metering block is the correct size.

However, if the mixture screws appear to have little or no control of the idle mixture richness, the idle feed restriction hole will have to be enlarged until turning the mixture screws causes the engine to run rough. The idle feed restriction hole should be enlarged only in steps of 0.002in, using numbered wire drills and a pin vice.

Once the mixture screws have some control of the idle mixture, very slowly turn the idle speed screw to bring the engine speed up to about 3,000rpm, or below the point where the main system comes into operation. Be certain to increase the engine speed very slowly so that fuel will not issue from the accelerator pump and cover up the lean mixture for which we are looking.

If the engine beat becomes splashy, or it seems to stumble as the speed is increased, a lean mixture condition is indicated. Try to correct this by turning out the mixture screws. If the screws have to be backed out more than half a turn from the mixture setting previously established, you will have to continue opening out the idle feed restriction holes by 0.002in at a time until there is no miss up to 3,000rpm.

Once the mixture is correct up to 3,000rpm with no load, you are ready to test the engine at a light load. Accelerate the car as slowly as possible from 15 to 35mph in the highest gear in which it will run without excessive transmission snatch. If it surges, the mixture is lean. As a cross-check, hold the car on a very light throttle at a steady 20mph, then a steady 25mph, and so on up to 35mph, in the highest gear possible, for half a mile at each speed on a smooth and level road. If the engine tends to surge, try turning the mixture screw out half a turn. If more than half a turn is required to fix the problem, then it is back to increasing the idle feed restriction hole size in 0.002in steps to richen up the idle mixture.

When you are carrying out all of the idle mixture testing and light-load running you will have to use fairly warm spark plugs to avoid false results from fuel-fouled plugs.

Three types of fuel bowls are used on the four-barrel Holley carburettors. Most high-performance models use a dual inlet, centre-pivot float, with external float level adjustment. This type of float and bowl is best suited to road circuit and speedway racing where high cornering forces are involved.

Many models use the side-hung float and bowl, with external float level

When it comes to bolting up a new Holley on your manifold there are few problems that you are likely to encounter. However, before you slam the hood closed after fitting the new carburettor, ensure that there is sufficient clearance between the hood and the carburettor. Also check that the accelerator pump lever is not fouling the manifold. When the 50cc pump is used, it is often necessary to use a 1/4in spacer to raise the carburettor. Lastly, ask someone to hold the accelerator pedal flat while you check that the throttle plates are opening fully.

In the world of motorcycles the Mikuni carburettor reigns the present king. Other carburettors are able to equal or even surpass the Mikuni in certain respects, but overall the Mikuni has much to offer those interested in a good power range and ease of tuning.

Most Japanese motorcycles leave the factory fitted with Mikuni constant velocity (CV) type carburettors, which work on the same principle as the SU carby. These carburettors are used to reduce exhaust emissions and improve fuel economy. However, they do stifle high rpm breathing and it is very difficult to obtain suitable needles and jets to tune them. Hence it is often advisable to replace these carburettors with slide-type Mikunis on modified engines. However, do not fall into the trap of replacing a CV carburettor with a slide-type of the same size or you will have a badly over-carburated engine. CV carburettors flow considerably less air than slide-throttle carburettors, so in general slide-type Mikunis approximately 4–6mm smaller will be required for road engines. Table 3.28 indicates the sizes required for radically modified engines.

Table 3.28 Recommended slide-type Mikuni carburettor sizes

Cylinder displacement (cc)	**Recommended carburettor size (mm)**			
	Semi-race	*Full race*		
		8,500rpm	*10,500rpm*	*12,500rpm*
125–150	24			26
175–200	28		29	31
225–250	32		34	36
275–300	34		36	
325–350	34	36	38	
375–425	36	38		
500–650	35	37		

Mikunis use two types of main jets. The hex-head jets are flow-rated in cc per minute, and jets from size 50 to 195 are available in steps of 5, and size 200 to 500 in steps of 10. The round-head main jets are aperture-sized; the largest jet available is a 250, with an aperture size of 2.50mm.

The needle jet uses a code to identify its size. The first number indicates the jet series; eg a 159 series jet fits a 30–36mm spigot mount Mikuni (Table 3.29). The letter-number combination below the series number shows the fuel hole size. The letter denotes the size in increments of 0.05mm and the number signifies size increments of 0.01mm; eg a P-4 jet would have a hole size of 2.670mm. There is one exception to this: the size –5 needle jet is 0.005mm larger than the –4 jet (Table 3.30).

Table 3.31a Mikuni series 6 needles

To fit all 30–38mm spigot-mount carburettors

Needle	X	Y	10	20	30	40	50	60
6H1	62.3	37.5	2.510	2.510	2.510	2.412	2.041	1.696
6DH2	62.3	28.0	2.511	2.511	2.466	2.295	2.000	1.660
6F9	62.3	28.9	2.516	2.516	2.475	2.210	1.949	1.678
6CF1	61.5	29.5	2.512	2.512	2.429	2.240	1.974	1.710
6FJ6	62.3	35.2	2.505	2.505	2.505	2.376	2.040	1.606
6DH3	62.3	22.0	2.512	2.512	2.458	2.286	1.948	1.607
6J3	62.3	36.7	2.515	2.515	2.515	2.359	1.912	1.456
6L1	62.3	37.0	2.512	2.512	2.512	2.335	1.826	1.313
6DP5	62.3	32.1	2.518	2.518	2.518	2.372	1.834	1.141
6N1	62.3	37.0	2.514	2.514	2.514	2.278	1.672	1.058
6DP1	62.3	28.9	2.511	2.511	2.476	2.312	1.748	1.075
6F3	60.5	34.2	2.512	2.512	2.512	2.313	2.050	
6DH4	62.3	25.5	2.520	2.520	2.440	2.258	1.915	1.575
6J1	64.0	36.2	2.517	2.517	2.517	2.339	1.919	1.495
6DH7	62.2	28.5	2.516	2.516	2.505	2.316	2.009	1.688

Note: X is the overall length of the needle in mm.

Y is the dimension from the top of the needle to the start of the taper.

The numbers 10–60 indicate the needle diameter in mm at points 10–60mm respectively from the top of the needle.

Table 3.31b Mikuni series 6 needles

To fit all 30–38mm spigot-mount carburettors

Needle	X	Y	Z	10	20	30	40	50	60
6F5	62.3	38.1	19.0	2.515	2.456	2.454	2.364	2.098	1.840
6F4	62.3	32.0	19.4	2.515	2.442	2.436	2.206	1.939	1.678
6F8	62.3	34.0	21.5	2.512	2.512	2.386	2.214	1.945	1.688
6FJ11	62.3	36.0	18.7	2.519	2.481	2.481	2.367	2.030	1.610
6F16	59.1	36.7	18.5	2.519	2.489	2.489	2.372	2.104	
6DH21	52.3	30.1	16.5	2.515	2.470	2.465	2.328	2.024	
6F16	64.6	31.2	18.4	2.520	2.404	2.400	2.201	1.941	1.679

Note: X is the overall length of the needle in mm.

Y is the dimension from the top of the needle to the start of the taper.

Z is the dimension in mm from the top of the needle to the pronounced taper point.

The numbers 10–60 indicate the needle diameter in mm at points 10–60mm respectively from the top of the needle.

The throttle slide cutaway size is indicated by the number stamped on the slide, eg 2.5 signifies a 2.5mm cutaway. The cutaway affects off-idle acceleration up to half-throttle. A large cutaway leans the mixture and a smaller cutaway richens the mixture.

The idle jet (or pilot jet) is available in sizes 15 to 80 in steps of 5. Fine

Table 3.31c Mikuni series 5 needles

To fit all 26–32mm spigot-mount and all 28–34mm flange-mount carburettors

Needle	X	Y	10	20	30	40	50	60
5D6	59.3	27.5	2.515	2.515	2.460	2.290	2.120	
5FJ9	59.2	35.0	2.517	2.517	2.517	2.364	2.021	
5D120	59.1	28.2	2.520	2.520	2.479	2.311	1.980	
5F3	58.0	27.4	2.519	2.519	2.419	2.135	1.863	
5EH7	57.6	28.5	2.517	2.517	2.473	2.210	1.848	
5E13	57.5	29.5	2.515	2.515	2.484	2.197	1.803	
5EJ13	57.8	26.5	2.519	2.519	2.431	2.210	1.766	
5DL13	60.2	32.0	2.515	2.515	2.515	2.362	1.922	1.463
5EJ11	60.3	28.5	2.515	2.515	2.515	2.241	1.839	1.420
5EL9	60.3	27.0	2.517	2.517	2.441	2.221	1.780	1.248
5FL11	60.3	28.2	2.518	2.518	2.438	2.175	1.740	1.256
5EP8	60.2	33.0	2.513	2.513	2.513	2.245	1.780	1.120
5FL14	58.0	28.0	2.520	2.520	2.440	2.170	1.735	
5FL7	58.0	28.0	2.518	2.518	2.440	2.170	1.735	
5DP7	57.6	26.4	2.512	2.512	2.440	2.259	1.580	
5J6	58.0	27.5	2.518	2.518	2.340	1.890	1.450	
5L1	58.0	27.0	2.518	2.518	2.330	1.811	1.297	
5C4	55.1	24.0	2.516	2.516	2.448	2.310	2.179	
5F18	58.0	27.0	2.521	2.521	2.515	2.257	2.006	
5J9	58.0	27.0	2.522	2.520	2.432	1.996	1.505	
5F12	51.5	23.3	2.021	2.021	1.882	1.631	1.375	
5D1	53.5	27.6	2.510	2.510	2.496	2.338	2.169	
5DP2	60.3	32.4	2.515	2.514	2.513	2.418	2.067	1.418
514	60.0	27.0	2.514	2.509	2.442	2.071	1.690	1.332
5D5	57.6	30.0	2.513	2.513	2.510	2.366	2.205	

Table 3.31d Mikuni series 4 needles

To fit all 18mm carburettors and 22 and 24mm flange-mount carburettors

Needle	X	Y	10	20	30	40	50
4D3	50.3	25.3	2.511	2.511	2.421	2.253	2.100
4D8	50.3	22.8	2.519	2.519	2.381	2.211	2.000
4E1	50.3	28.0	2.515	2.515	2.345	2.127	1.924
4DG6	50.3	24.0	2.518	2.518	2.405	2.119	1.850
4DH7	50.3	23.0	2.518	2.518	2.386	2.098	1.790
4F15	50.3	26.5	2.512	2.512	2.400	2.120	1.881
4J13	50.2	24.0	2.513	2.513	2.230	1.800	1.400
4L6	50.3	24.5	2.515	2.515	2.178	1.660	1.190
4F6	50.5	25.3	2.514	2.514	2.406	2.145	1.876
4L13	45.1	25.0	2.518	2.516	2.339	1.842	
4F10	50.2	24.5	2.513	2.513	2.385	2.135	1.877
4J11	41.5	21.3	2.512	2.506	2.188	1.776	
4P3	50.5	25.0	2.510	2.506	2.436	2.284	2.122

adjustment of the idle mixture is by means of the idle air screw, which richens the idle mixture when turned in (clockwise).

The float level is adjusted with the fuel bowl removed and the carburettor inverted (Figure 3.13). With the float tongue contacting the needle valve the distance 'A' should be equal to the specified float level. Usually this will be 25 to 35mm, depending on the carburettor type. Some Mikuni carburettors have the float level adjusted to dimension 'B'; in this instance the level is usually around 9 to 10mm; again this varies from model to model.

Many enthusiasts first attempt to tune the Mikuni by trying to determine the correct main jet size. This procedure is correct, but only if the engine has not been extensively modified and the stock carburettor is being used. If you find that large changes in the size of the main jet do not seem to be having very much influence on the half and full throttle mixture strength, you can be fairly certain that the needle jet is too small.

When the engine has been extensively modified I prefer to begin testing (after adjusting the float level) with the main jet removed. If the engine will just run at part throttle, but floods as the throttle is opened, the needle jet is close to the right size. However, if you find that the engine keeps going at three-quarters to full throttle, you can be sure that a larger needle jet is required. This test should be done with the needle lowered to the No 1 (ie lean) position.

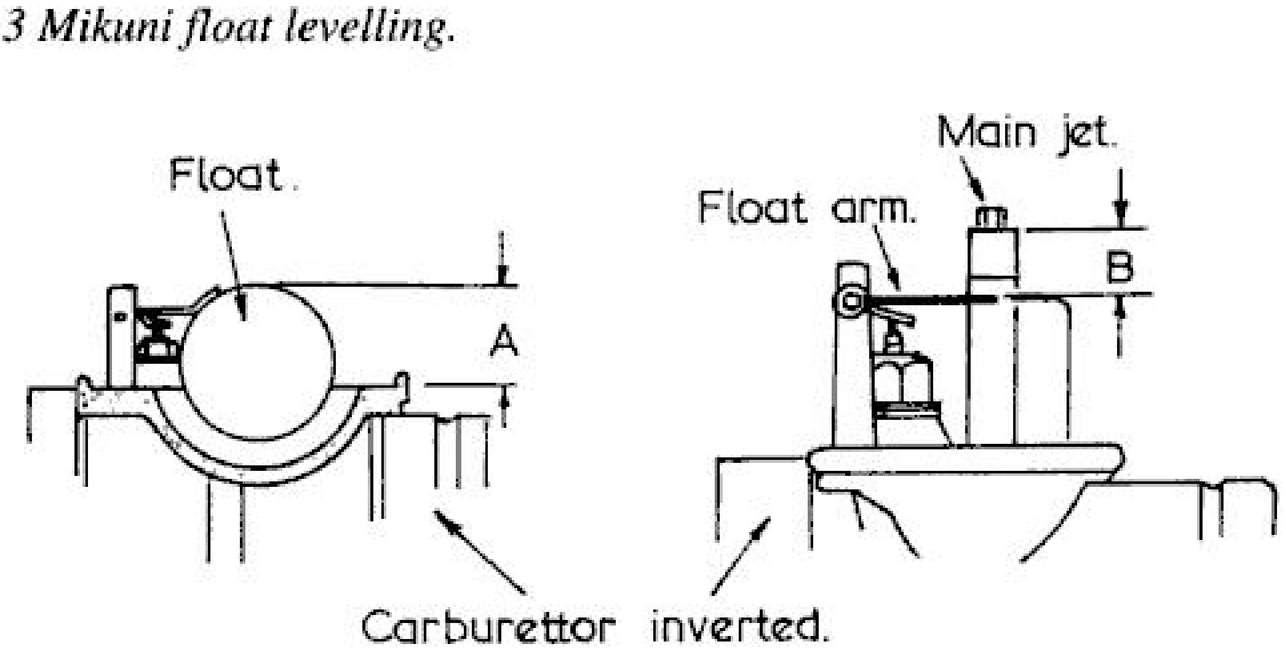
After you have found a needle and needle jet combination that is too rich, you can then try various sizes of main jets until you find one that allows the engine to run reasonably well at full throttle; do not worry about throttle response or acceleration for the moment. Carry out this test with the needle raised to the middle position.

Next find what size of idle jet (pilot jet) is required. Start these adjustments by backing out the idle speed screws until the throttle slides are completely closed, then turn the screws back in until the slides just open.

Having done that, close the idle air screws completely and back each one out 1 to 1½ turns. Start the engine and attempt to obtain a smooth 1,000rpm idle by juggling the idle air screws and the idle speed screws in turn. If you can get the engine to settle down to a good idle, synchronise the throttle slides using a set of vacuum gauges or the multiple-column mercury balancer described later.

If the engine will not idle, it is probable that the idle jets are wrong. Jets that are too small are indicated by an increasing idle speed as the air screws are turned in.

Figure 3.13 Mikuni float levelling.



When the idle jet are of the correct size turning the screw in should cause the engine to run faster at some point (usually 1 to 1½ turns from being fully closed). An idle jet that is too large is indicated by an ever-increasing idle speed as the air screws are backed out further and further. The air screw must not be opened more than 3 turns.

When the correct idle jets have been established, the throttle slides should be synchronised. Once this has been done, you can test that the cutaway is of the correct height. This influences the mixture from off to one-quarter throttle, so if the engine stalls or coughs and dies when the throttles are cracked open, change to slides with less cutaway (ie richer).

When you have settled on the correct slides, re-check the slide synchronisation and determine that the idle jet is still the correct size. Generally, a change of idle jet size is necessary only when a large change in slide cutaway height has been made.

With the idle jets, needle jets and slides finally selected and synchronised, you are ready to begin fine tuning.

First, check that the main jet is approximately correct by testing the bike at three-quarter to full throttle. If the engine runs well and the plugs read a good colour, the main jet is close enough to begin finding the correct needle profile and/or position.

The needle taper and position control the fuel/air mixture between one-quarter and three-quarter throttle. To determine if a change is required, test the bike on a smooth and level road for at least half a mile at one-quarter throttle, then at a half and three-quarter throttle. If the engine snatches and surges at a steady throttle opening, the mixture is too rich, so lower the needle one groove at a time until smooth running is achieved.

Next, try steady accelerations from one-quarter to half throttle and from half to three-quarter throttle, and note whether the engine appears to be rich or lean. Repeat the test but snap the throttle open each time.

You may find that the mixture is lean at one-quarter throttle and changes to rich between half and three-quarter throttle. This would indicate that the needle's taper is too steep, so change to a needle with a smaller angle of taper. Obviously a mixture condition the opposite of this would require a needle with more taper (ie a larger angle).

Once the correct needle has been determined, the bike should be tested at three-

Table 3.32 Mikuni metering guide

	Throttle-opening position					
	0	1/8	1/4	1/2	3/4	Full
Slide cutaway	A	A	B	B	D	D
Pilot or idle jet	A	A	B	D	D	D
Pilot air screw	A	A	B	D	D	D
Needle jet	B	A	A	D	D	D
Needle taper	D	B	A	A	D	C
Needle position	B	B	A	A	D	D
Main jet	D	D	D	D	B	A

The letters A–D indicate metering effectiveness at various slide openings.
A = most effective B = fairly effective C = small influence D = no influence

Mount the tubes on the face board with the tops of each tube protruding approximately 1in past the top of the board, and their bottoms level. The tubes may be mounted by drilling a number of 1/16in holes in the board and inserting copper wire through the holes and around each glass tube.

Once the 'U' tubes are secure, they should be filled to the zero line (the halfway point) with mercury; about 10cc will be required in each column. Mercury is a very dangerous accumulative poison and as such it is not easily obtained in many countries. At times it can be bought from laboratory supply firms, but generally you will have to know someone who has the right contacts, for example a chemistry teacher or an electrician who has access to old mercury switches.

Because mercury is deadly, never handle it or breathe its vapour. It appears to be stable but actually it is very volatile, giving off poisonous vapour continually. Therefore when the balancer is not in use, stop up the ends of the tubes or connect the two ends together with rubber hose, to prevent the escape and build-up of vapour in your workshop. Always keep the balancer locked away from children or pets. Remember the poison is accumulative, which means that it builds up in your body. When the concentration reaches a certain level it will cause blindness, insanity or death.

To connect the 'U' tubes to the inlet manifold you will need 9ft lengths of 1/4in i/d surgical rubber hose. This length and type of hose provides the necessary damping without impairing the accuracy of the readings. Note that the hose is connected to one end of the 'U' tube, the other end being open to the air.

The final connection from the hose to the vacuum test holes in the manifold is made using adaptors produced for this purpose by the manufacturer of your machine, or you may choose to make a set of adaptors yourself.

The balancer is very easy to use. You merely adjust the slide opening of each carburettor to get an even reading in each mercury column. Once the slides have been synchronised, the idle speed and mixture are then adjusted for the best idle.

Bikes with an individual throttle cable to each carburettor can be a problem, so after the initial synchronisation the carburettors should be checked for balance at several rpm levels. Changes in balance indicate sticky slides or uneven cable pulls.

This balancer is not just for bikes. The triple and quad Weber set-ups and those carburettors with air screws are also best tuned using this multi-column manometer.

Chapter 4

Electronic Fuel Injection

Electronic fuel injection (EFI) is a rather frightening concept for tuners who have grown up working with carburettors. However, in practice there are many similarities between a carburettor-type fuel delivery system and an EFI system. Additionally the very same laws of physics work in exactly the same way with either system. Thus, just as large-diameter manifold runners kill low rpm torque while increasing top-end hp with carburettors, we likewise see the very same thing with EFI. In a similar vein, when we increase carburettor throttle plate size, say swapping from a pair of 45DCOE Webers with 45mm throttle bores to 48DCOEs with 48mm throttle bores, we increase both high rpm air flow and maximum power at the expense of a fall in mid-range output. With EFI we see the same sort of thing when we replace a throttle body with 45mm throttle plates with a larger-bore body with 48mm plates. Also, just as finely atomised fuel droplets issuing from a carburettor to be evenly distributed throughout the intake air charge burn more uniformly to produce more power, so likewise with EFI.

Clearly the major difference between the two systems is with regard to fuel metering. The carburettor relies on a series of jets with correctly sized metering orifices to deliver the correct quantity of fuel into the intake air stream. This occurs because of the pressure differential existing, with the inlet tract being subjected to a vacuum, and fuel in the carburettor's float bowl being acted on by normal air pressure, pushing the fuel through the various jets into the intake air. Electronic fuel injection is different in that the central brain or computer, which we call the electronic control unit (ECU), calculates how long it will open the fuel injector nozzles to deliver the correct quantity of fuel into the intake air stream, based on information that it is receiving from various sensors.

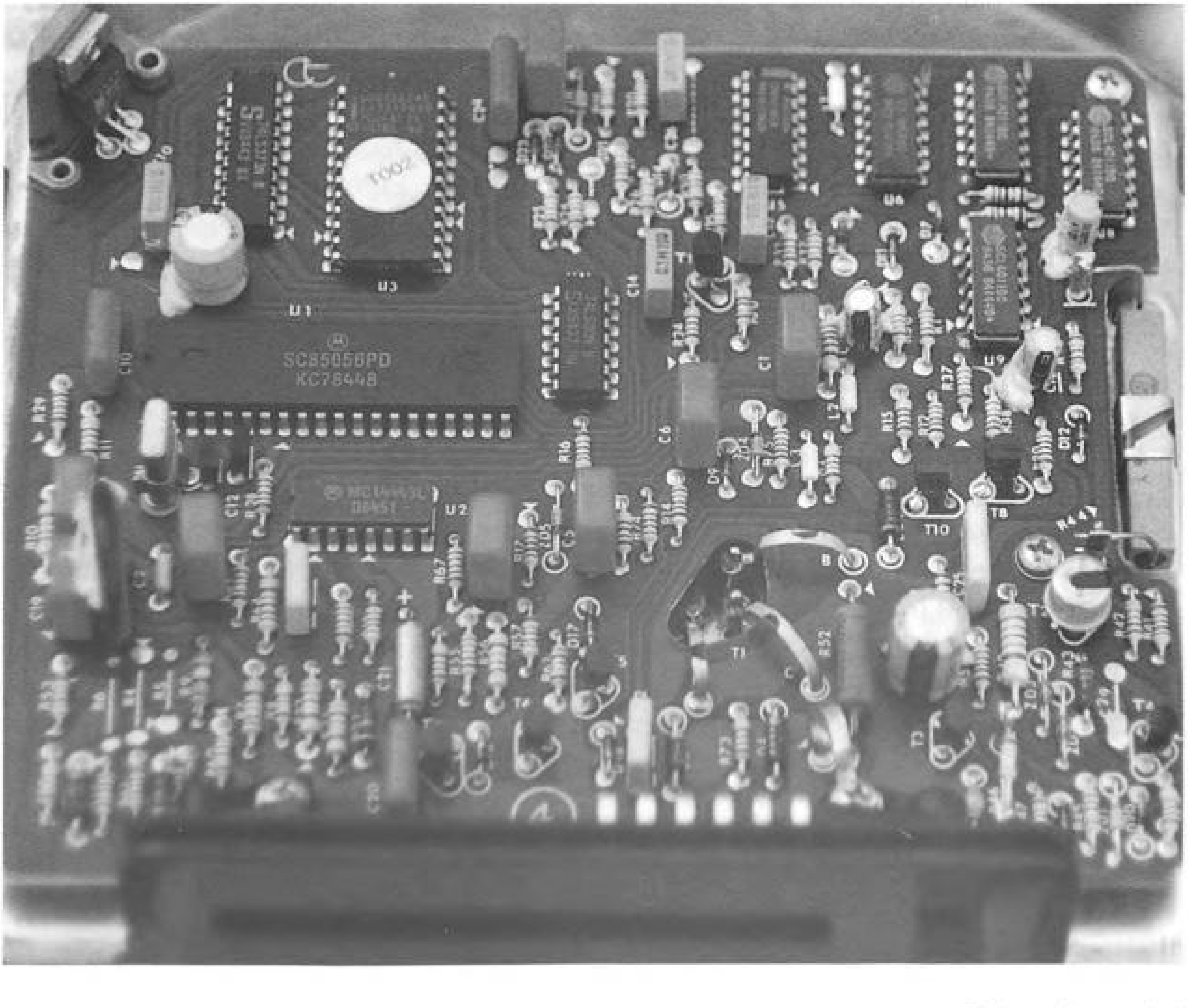
The correct length of time that the injectors must spray, called the 'pulse width', is determined during extensive dyno testing of the engine. For example, if at wide-open throttle the engine makes 300hp at 8,000rpm with the injectors open for 8.72 milliseconds, and makes 305hp with a pulse width of 8.64 milliseconds, then drops to

302hp when the pulse width is reduced to 8.58 milliseconds, the ECU will be 'told' that at wide-open throttle and 8,000rpm the engine must be given an 8.64-millisecond injector spray period so as to ensure that the engine makes best hp. This process, which we call 'mapping', is continued under every possible combination of operating conditions that the particular engine is ever likely to experience.

When car manufacturers start such mapping tests the process can take 12 months and cost a couple of million dollars because they have to meet exacting standards of not only engine performance, but also driveability, economy and government emissions requirements. Competition engines, however, are far less demanding, and even when you are working with an engine with which you are not too familiar it is possible to generate a basic fuel map in a couple of days. (Figure 4.1)

The fuel map thus generated in effect becomes a 'library' that is programmed, using a laptop computer, into the ECU's memory. From this information store the ECU 'knows' exactly how long the injectors must remain open, spraying fuel, for literally hundreds of engine operating conditions. Citing our previous example, when sensors relay to the ECU that the engine is spinning at 8,000rpm and the throttle is wide open, the ECU instantly files through its library of stored information and finds that the injectors should spray for 8.64 milliseconds. The ECU immediately sends out

The ECU receives signals from various sources, then computes the appropriate injector 'pulse width'.



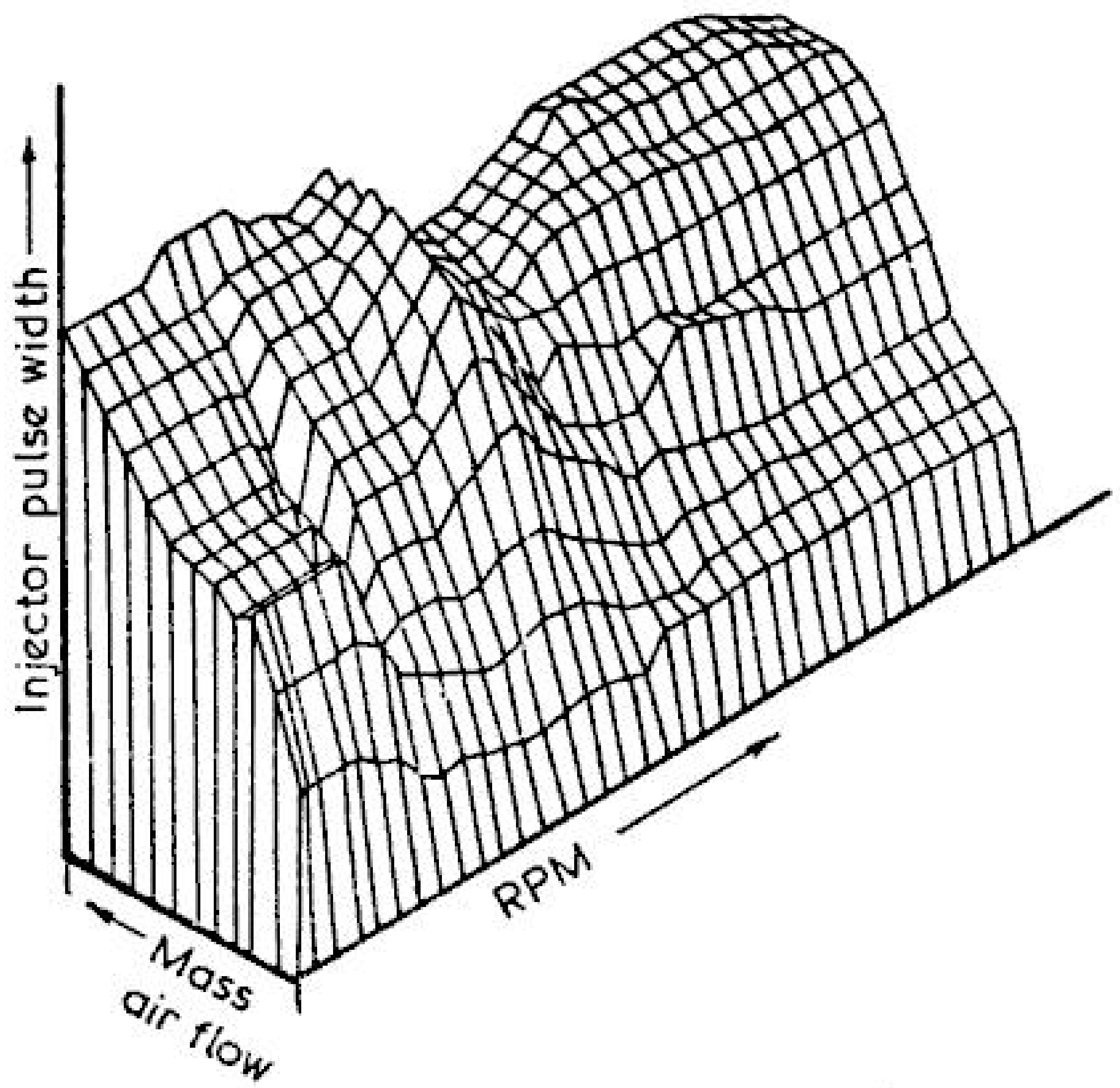


Figure 4.1 An EFI fuel map.

an electrical current to pulse the injectors for precisely 8.64 milliseconds. Along with this map reference point the ECU will have anywhere from 120 to 800 other map reference points placed in its memory enabling it to provide the correct injector pulse width for any operating condition the engine is going to encounter.

From this you will appreciate that before the ECU can determine the appropriate injector pulse width it must first be provided with information about what the engine is actually doing, and in particular precisely how much air is flowing into the cylinders at that particular moment. There are a number of methods that we can use to determine air flow into the engine: we can measure it using an air flow meter; we can calculate it based on engine rpm and manifold vacuum levels; or we can calculate air flow from the engine rpm and the throttle plate open angle. As each system has its advantages and disadvantages we will look at each in turn.

The first arrangement using an air-flow meter is what we call a 'mass air flow' system. The earliest air-flow meter, often called a vane air-flow meter, is a simple unit that passes the air flowing into the engine through a passage blocked by a spring-loaded flap (Figure 4.2). As the air flows through the meter it 'blows' the flap open to a certain angular position, dependent on the force of the spring and the amount of air flowing in the passage. Connected to the flap pivot is a variable resistor, a potentiometer, which changes the ECU's input voltage according to how wide the flap has been swung open.

Remember that air density changes with the ambient temperature, as well as other factors, so air-flow input in itself is not adequate for accurate fuel metering. Thus the air-flow meter also houses an air temperature sensor, and this signal, along with the air-flow signal, is used by the ECU to calculate mass air flow. You will note that this air-flow meter also has a bypass passage with a mixture adjusting screw. By

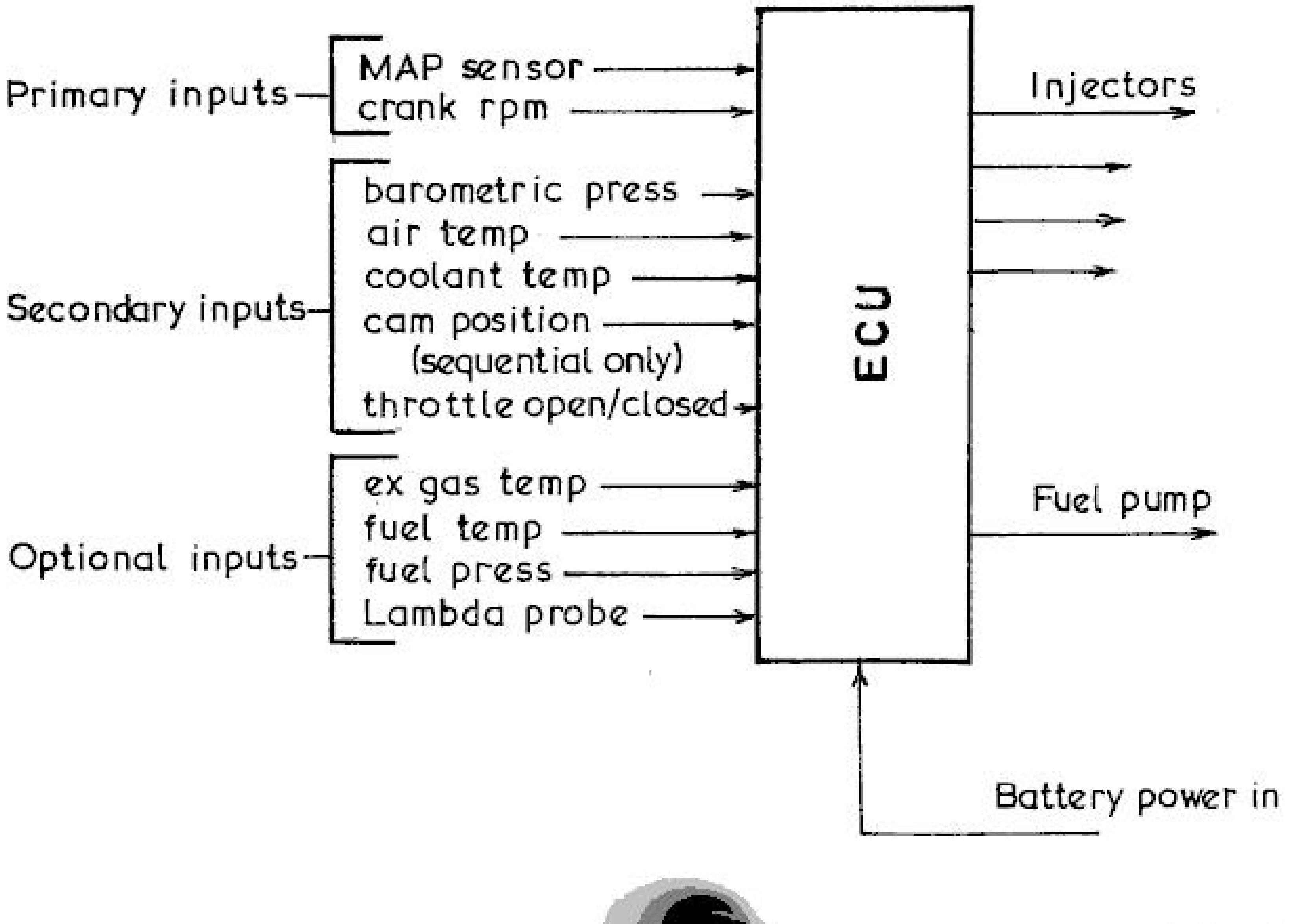
To get around the high cost factor of air-flow meters, manufacturers developed the speed density system. In this system there isn't any air-flow meter to provide information about air flow into the engine to the ECU. Rather the ECU uses manifold vacuum and engine rpm as the central keys to establishing the engine's fuel requirements. In addition the ECU also receives input from the air charge temperature sensor and the barometric pressure sensor (Figure 4.3).

The advantage with this arrangement is that there is no air-flow meter to cause any flow restriction, and the manifold absolute pressure (MAP) sensor will respond to both positive and negative manifold pressures. Thus the system is well suited to turbo and supercharged applications. However, wild camshafts that cause strong reversion pulses in the inlet tract can give rise to metering difficulties with the speed density system.

The third type, the Alpha-N system, was originally developed for competition engines. The primary ECU inputs for determining inlet air flow come from the engine speed sensor and the throttle position sensor (Figure 4.4).

The advantage with this system is again that there is no air-flow meter involved, so there are no obstructions to air flow. Also, with no manifold pressure sensor being required, the Alpha-N arrangement is immune to metering difficulties caused by either low or wildly fluctuating manifold vacuum levels and massive reversion pulses. However, this does not mean that it is totally free of metering problems. With this system accurate throttle position input is important because the assumed air flow into the engine is based on the exact throttle plate open angle, and the engine speed. This is not a worry with competition engines, but with road cars the first few degrees of throttle opening are most important for ease of driving. However, it is in these first few

Figure 4.3 Speed density type fuel injection.



Compensation for ram air

On race cars running at high speeds a significant supercharge effect can be induced in the inlet tract by connecting a large forward-facing air scoop to the cold air box. However, unless the ECU is kept informed of this rising level of air flow into the engine, which increases according to car speed, the fuel/air mixture will lean out, resulting in lost hp and most probably engine damage. Additionally, if the car is following in the slipstream of another car this throws another variable into the equation.

Obviously we cannot accurately simulate the ram air effect when we are building up the fuel map on the dyno. The simple alternative is to measure air pressure within the cold air box just as we would for a turbo or supercharged engine, then programme the ECU to adjust the injector duty cycle to compensate for changing air box pressure. To perform this function we would have a MAP sensor relaying air box pressure information to the ECU. Then, when pressure in the air box increased, the ECU would lengthen the injector duty cycle to maintain the correct fuel/air ratio, and it would also retard the spark to avoid detonation.

This sounds simple enough, but it takes a considerable amount of track testing to programme the ECU to adjust correctly the base fuel and ignition maps to compensate for ram air. Clearly, for ram air to deliver the desired power increase it must be done correctly otherwise it could cost hp or even the engine!

To give some indication of where we are heading with this kind of tuning, we really need data acquisition from a Lambda probe to show what the engine's air/fuel ratios are on the parts of the circuit where the engine is on full throttle for several seconds, accelerating hard. If we had best hp on the dyno with an average air/fuel of around 13.2:1 at full throttle and now, from our data logging, we find that MAP sensor trim at high speed is richening the air/fuel to 12.5:1, we would then reduce MAP compensation to lean the mixture back closer to 13.2:1.

Note that to save time when tuning from a Lambda we usually do not think in terms of air/fuel ratios – we simply work straight from the Lambda reading rather than converting back and forth. A Lambda number of 1.0 equals an air/fuel ratio of 14.7:1 (Lambda x 14.7 = air/fuel ratio). Therefore we would be looking at maintaining the Lambda at about 0.895, with a maximum richness around 0.86 and a minimum of 0.93.

power, while single-plane manifolds with their larger, short runners gain top-end power at the expense of the bottom end.

Table 4.2 illustrates how well an Edelbrock Victor Jr single-plane manifold performed on the 5-litre Mustang discussed earlier. This manifold had a Harrop four-blade 1,000cfm throttle body bolted on in place of a four-barrel carb. Close to where the runners meet the cylinder heads they were milled and eight fuel injector bosses welded in place to ensure that the injectors sprayed at the correct angle down each inlet port. When you compare the results with what was obtained with the isolated runner manifold in Table 4.1 you can see that there is not a great deal in it up to 6,000rpm, but at the power peak the isolated runner manifold, by virtue of its greater air-flow capacity, is about 3.2% stronger, and at maximum engine speed makes 1.9% more hp.

Table 4.2 also shows that in absolute hp terms fuel injection does not make a whole lot more power than a well-sorted carburettor set-up; typically the hp difference at wide-open throttle will be 2–3%. However, when it comes to responsiveness,

Table 4.2 Comparison of Ford Mustang 5-litre fuel injection versus carburettor

	Test 1		**Test 2**	
rpm	**hp**	**Torque**	**hp**	**Torque**
4,500	284.2	331.7	284.8	332.4
5,000	315.3	331.2	315.0	330.9
5,500	387.3	369.8	378.4	361.3
6,000	420.5	368.1	421.0	368.5
6,500	439.9	355.4	441.8	357.0
7,000	440.5	330.5	431.3	323.6
7,500	416.0	291.3	400.6	280.5

Test 1 – Edelbrock Victor Jr manifold with Harrop 1,000cfm throttle body.

Test 2 – Edelbrock Victor Jr manifold with Holley 750cfm carburettor.

driveability and part-throttle performance, properly sorted fuel injection on a correctly sized inlet manifold will always be way ahead of any carburettor set-up.

However, making power is not just about air flow, as I have pointed out in earlier chapters. There is also fuel atomisation and distribution to be considered, and here the isolated runner arrangement offers the tuner a good deal more freedom in that he can take the engine closer to the limit of its hp-producing capabilities while still maintaining engine reliability.

Some people have the idea that fuel injection delivers fuel droplets of exactly the correct size into the air stream, and that these droplets perfectly homogenise with that inflowing air and will later burn at exactly the correct rate to produce maximum power. Such a theory is very easily disproved by the fact that injection systems invariably inject more fuel when the engine is cold. This is done because only a percentage is in combustible droplet size and mixed in combustible proportions with the surrounding air at the time that the spark plug fires. When the engine is hot the air and the fuel droplets gather heat from the inlet tract, the cylinder walls, the piston crown, the combustion chamber, the valves and the spark plug. This serves to improve fuel atomisation, so with a greater percentage of very fine fuel droplets in contact with oxygen molecules during the combustion phase, the ratio of fuel droplets to oxygen molecules becomes excessive; the mixture is too rich. Therefore to avoid such a waste of fuel, and the loss of power, the injection pulse width is progressively cut back as the engine heats up to normal operating temperature.

What has this got to do with isolated runner manifolds? Well, at high engine speeds the inlet tract of a race engine is not a lot different from the situation I have just described that exists in a cold engine. We have to use big injectors to spray sufficient fuel in the short time available. This means that the fuel droplets entering the air stream are larger than those from smaller injectors spraying for a longer period of time in an engine operating at low rpm. The result is a larger portion of non-combustible droplets, which marginally upset the combustion process, with the result of reducing engine performance.

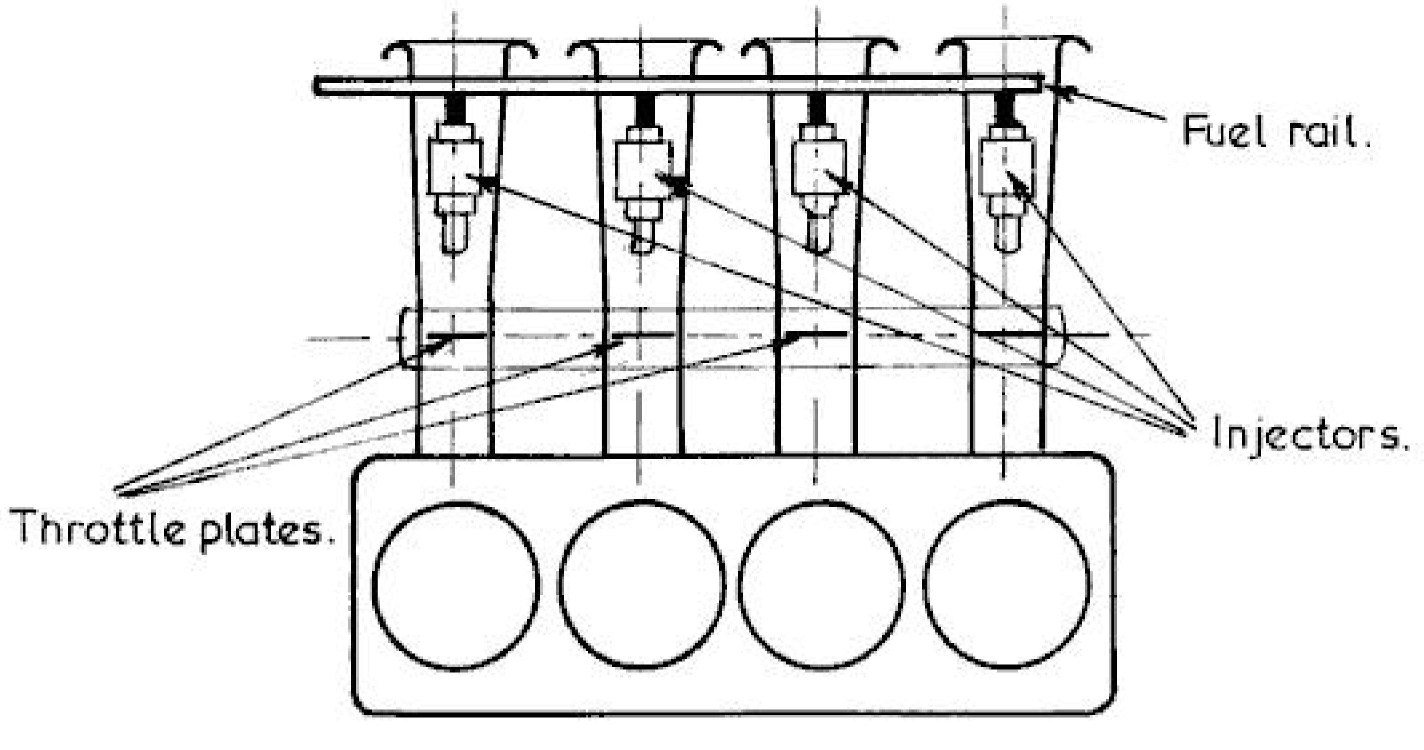
One way that we can improve this situation is to move the injectors further away from the engine, and if we use a sequential system we can even mount them outboard of the throttle plates (Figure 4.6). In stock engines we are used to seeing injectors mounted close to the head and spraying right at the back of the hot inlet valve. This improves atomisation, stopping the fuel dropping out of suspension and not burning at low rpm when air speed in the inlet tract is slow. Also 'inboard' injectors improve low speed and mid-range rpm throttle responsiveness, and in batch fire systems they stop charge robbing.

However, with a race engine running sequential injection we do not have such a problem so we can move the injectors way out to the intake trumpets. From this location some of the fuel droplets entering the air stream will smash into the throttle plate and be broken down in size. Other droplets will collect some heat on their relatively long journey down the inlet tract and this will also aid atomisation. Additionally, introducing the fuel into the inlet stream a long way from the valve allows extra time for the fuel droplets to more evenly mix with the air as it swirls around the throttle plate and down the inlet tract. Thus with improved fuel atomisation and better mixture homogenisation we gain some power, and with improved combustion control the possibility of running more compression or leaning the mixture opens up, with another small power gain probable.

Another way in which we can gain some power with the isolated runner manifold is by turning the throttle body upside down, or rather than turning it through 180° we may turn it through 90° or 270°. Moving the throttle body like this changes the directional effect that the throttle plate imparts to the fuel/air mixture flowing over its surface. This can serve to increase hp in two ways; it may bias air flow to a particular side of the intake tract and increase the quantity of air passing into the cylinder, or it may change the swirl characteristics of the inlet tract, improving fuel and air homogenisation and thus improving the quality of the fuel/air charge entering the cylinder.

An isolated runner manifold opens up yet another possibility for increased power due to improved combustion. Earlier we saw how small injectors spraying for a longer period deliver more finely atomised fuel droplets into the inlet air stream. With an isolated runner manifold we can take advantage of this situation by running two small injectors, placed in two different locations along each inlet tract, spraying the same

Figure 4.6 Isolated runner manifold with outboard injectors.



make more power at nearly every point between 5,000 and 7,500rpm. Down at 5,000 and 5,500rpm the engine is a very useful 20hp stronger, and at the very top of the rev range it only loses 5–10hp to the bigger 48mm throttle bodies.

Table 4.3 Throttle bore comparison on a 16-valve 2-litre Nissan

	Test 1		Test 2	
rpm	**hp**	**Torque**	**hp**	**Torque**
4,000	93.7	123.0	94.2	123.7
4,500	116.2	135.6	116.5	135.9
5,000	147.9	155.4	128.3	134.8
5,500	166.4	158.9	148.1	141.4
6,000	186.3	163.1	179.6	157.2
6,500	191.7	154.9	202.0	163.2
7,000	209.6	157.2	211.8	158.9
7,500	226.4	158.5	220.5	154.4
8,000	229.8	150.9	235.4	154.5
8,500	218.5	135.0	228.1	140.9

Test 1 – 45mm-bore throttle bodies.

Test 2 – 48mm-bore throttle bodies.

Note: in both tests the same inlet manifold was used, which tapered from a 48mm bore down to match the inlet port.

Suzuki learned the same lesson with their 130hp (155hp in race trim) GSX-750R. It was introduced with huge 46mm throttle bodies, but because of poor throttle response and sluggish mid-range these were replaced by 42mm units. As a further admission of the need for inlet tract air speed Suzuki added a second throttle plate in each inlet tract, progressively opened by the ECU.. The throttle bore sizes recommended in Table 4.4 will serve as a reliable guide in enabling you to select throttle bodies with a bore size close to that with which the engine should work best.

Table 4.4 Recommended throttle body sizes

Throttle bore dia (mm)	hp of one cylinder
36	27–37
40	35–46
45	43–56
48	50–65
52	60–77
56	70–87
62	80–98

Together with the bore of the throttle body we have to consider the length of the inlet tract. Just as the tuned length of exhaust headers can be beneficially used to alter the power characteristics of a competition engine, so also the length of the inlet tract can be adjusted, using various-length intake trumpets, to modify the engine's power curve.

Generally, when we add length to the inlet tract we expect to see a hp increase at the bottom of the power band, along with some reduction in hp at the peak. Conversely, when we take length away we may add power at the peak while knocking something off the bottom end. However, if we go too far in either adding length, or in taking length off, we will probably lose power at full throttle right across the power band.

Table 4.5 shows how taking just 15mm off the length of the intake tract of the Nissan rally engine mentioned earlier lost an average 3–4hp right across the engine's operating rpm range. However, this engine responded in the classic manner when 25mm was added. At 5,500rpm it was 9hp stronger, but peak power was down over 4hp, and at the engine red line it is down 7hp. In a circuit racer or tarmac rally car this sort of loss would not be acceptable except on a very tight track, or perhaps if the car was running with less than ideal gearing. However, in the forests this engine with the long trumpets was on average 0.3sec faster per mile.

Table 4.5 Inlet trumpet comparison on a 16-valve 2-litre Nissan

	Test 1		**Test 2**		**Test 3**	
rpm	**hp**	**Torque**	**hp**	**Torque**	**hp**	**Torque**
4,500	112.1	130.8	116.2	135.6	118.8	138.7
5,000	143.3	150.5	147.9	155.4	151.2	158.8
5,500	163.2	155.8	166.4	158.9	175.6	167.7
6,000	184.2	161.2	186.3	163.1	190.8	167.0
6,500	187.3	151.3	191.7	154.9	193.3	156.2
7,000	206.6	155.0	209.6	157.2	207.3	155.5
7,500	224.5	157.2	226.4	158.5	223.8	156.7
8,000	227.1	149.1	229.8	150.9	225.3	147.9
8,500	217.2	134.2	218.5	135.0	211.4	130.6

Test 1 – 60mm-long trumpets.

Test 2 – 75mm-long trumpets.

Test 3 – 100mm-long trumpets.

However, not all engines react in the 'normal' way. The 5-litre Chev circuit engine referred to in Table 4.6 was running in a restricted compression class (10.5:1) with a 7,500rpm rev limit. During the course of testing this engine appeared to be pretty much insensitive to induction tract length, showing virtually identical hp at all rpm points right the way from 3,750 to 7,500rpm running with 75mm, 60mm and 45mm trumpets. However, when trumpets 100mm long were tried the power shot up, not at the bottom of the power band, but right at the peak!

As for the overall inlet tract length, somewhere between 310 and 330mm is a good starting point. This measurement is from the start of the trumpet down to the valve seat, and it seems to work for many engines producing maximum hp at anything from 7,000 to 8,500rpm.

The next area we need to take a look at is the actual timing of the injector spray period. In the batch fire type system all the injectors spray simultaneously once every revolution of the crankshaft, ie each injector sprays twice during each complete engine cycle (Figure 4.8). In a four-cylinder engine the firing of the spark plugs for cylinders

Table 4.6 Inlet trumpet comparison on a 5-litre Chev

	Test 1		Test 2	
rpm	**hp**	**Torque**	**hp**	**Torque**
3,750	255.9	358.4	258.3	361.8
4,000	292.2	383.6	290.9	382.1
4,500	331.8	387.3	335.0	391.0
5,000	403.0	423.3	401.2	421.4
5,500	466.6	445.6	468.1	446.9
6,000	500.0	437.7	505.4	442.4
6,500	553.3	447.1	550.4	444.7
7,000	584.2	438.3	587.9	441.1
7,250	591.4	428.4	604.6	438.0
7,500	588.5	412.1	611.7	428.3

Test 1 – 60mm-long trumpets.

Test 2 – 100mm-long trumpets.

1 and 4 triggers the ECU to commence the spray period for all the injectors, which is why this system is usually called batch fire injection.

Thus while this arrangement results in the injectors sometimes firing when the inlet valve is closed, it does have the benefit of simplicity. Additionally, the fact that they pulse twice allows for the use of smaller injectors. This reduces their cost, but the other benefit is that at lower rpm and light engine loads the injector spray period can be made longer by programming the ECU to skip every second firing, ie the injectors only fire once every two revolutions of the crankshaft. This improves metering precision as most injectors become erratic and lose metering precision when the pulse width is reduced much below about 2 milliseconds.

Intake chokes

Tuners usually associate chokes with Weber carburettors having a removable air venturi, which is available in a variety of bore sizes, to tune the carburettor to suit the air-flow characteristics and power requirements of the engine. Before teams had the vast sums of money they have today to enable them to build engines to suit specific race circuits, or in the case of rally cars to build engines to suit specific types of rallies, they had to make do with engines in just one or two levels of tune. However, to change the power characteristics an interesting tuning device was hidden away in the inlet manifold; while the throttle bodies may have had a bore of, say, 48mm, concealed behind the throttle body in the inlet manifold were removable 'chokes' that may have necked the manifold bore down to 45mm on circuits where more low-speed grunt was required. Then on very-high-speed circuits a plain 48mm bore sleeve without a venturi would be fitted.

Intake chokes work very well, but do pattern your chokes after the way Weber and Dellorto shape the venturis in their chokes. You will probably only want to use one or two choke sizes in competition, even though you may check three or four sizes going down in 1.5 or 2mm steps while running on the dyno. Remember that you will require a different map in the ECU for each size; a dash-mounted switch will make programme selection simpler.

The pulse width and duty cycle relationship

As engine rpm increases, the time available in which to complete the injection of fuel into the intake air stream becomes shorter and shorter. Obviously an engine running wide-open throttle at 9,000rpm has only two-thirds of the amount of time in which to get injection completed compared with an engine running at 6,000rpm. However, an injector cannot be held open continuously or it will burn out. In a modified road engine it can be active, or on 'duty', up to 85% of any given time period – this is termed its duty cycle. Clearly its 'rest cycle', where there is no electricity passing through the solenoid winding, accounts for 15% of that fixed time period. Because stock road cars seldom see extended high-rpm, wide-open throttle running, some manufacturers allow up to a 93% duty cycle, but in competition engines, which run at reduced throttle opening for only short periods of time, we should not extend the duty cycle beyond 80%.

This necessary 20% rest cycle impacts on the time that the injector has available in which to pulse and spray fuel into the air stream. We can calculate the maximum permissible pulse width using this formula:

$$\text{Maximum pulse width (milliseconds)} = \frac{M \times 60{,}000}{\text{rpm}}$$

where M = injector duty cycle, and rpm = maximum rpm for batch fire, and half maximum rpm for sequential injection.

If during dyno testing we find from our pulse width meter that the injectors are going beyond an 80% duty cycle at any engine speed, we will have to fit larger injectors or increase the fuel pressure. However, remember that the maximum permissible pulse width increases at lower rpm:

Maximum pulse width (milliseconds)

rpm	**70%*	*80%*	*85%*
4,500	18.67	10.67	11.33
5,500	15.27	8.73	9.27
6,500	12.92	7.83	7.85
7,500	11.20	6.40	6.80
8,500	9.88	5.65	6.00
9,500	8.84	5.05	5.37

*Indicates sequential injection; the 70% duty cycle is suggested as a maximum for best hp. However, the injectors can stay open for an 80 or 85% duty cycle providing 16ms is not exceeded.

Note, however, that in general injectors will not pulse for longer than 16 milliseconds. This usually is not a concern with naturally aspirated batch fire engines, but turbo and supercharged batch fire engines, which produce very high torque at low rpm, can run into trouble here, as can all engines running sequential injection.

Thus a 280hp non-turbo engine with four cylinders requires about 322cc of petrol per minute per cylinder to produce that hp.

The next step is to take a look at what size injector we require to provide that flow of 322cc/min while keeping the duty cycle down to our required figure, using this formula:

$$\text{Injector static flow (cc per minute)} = \frac{TF \times 100}{N \times M}$$

where TF = theoretical flow, N = number of injectors per cylinder, and M = injector duty cycle.

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