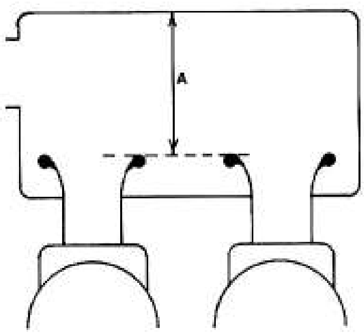
CHAPTER 2. BREATHING - THE INDUCTION SYSTEM.

AIR BOXES AND CLEANERS.

The need to use an air box at all must be judged by the environment surrounding the engine and in which the vehicle is going to be used.
For example, while it is unlikely that a motorcycle needs any additional cold air fed into the carbs, the engine compartment of a car is often very hot and poorly ventilated, so the argument for an air box here is to get cold air from the front of the car, under the bonnet to the carbs.

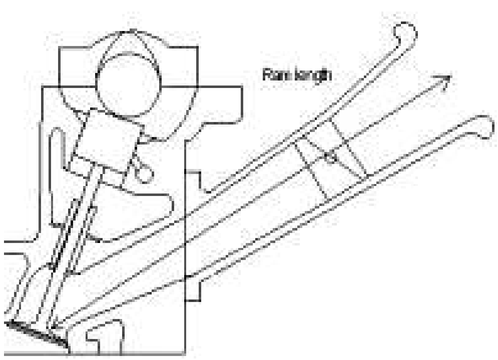
On the other hand, if the bike or car is going to be used in excessively dusty or sandy conditions, then an air box and filter are essential.
General rule of thumb is that vehicles used for pure circuit work or fast roadwork, including dragsters, in Europe, can do without any air box at all, except during the occasional long hot summer when the dust level is high.
This all supposes that you are prepared to put up with the induction roar of unsilenced intakes.

It goes without saying that autocross, rally, dirt and grass track vehicles all need cleaners. The important thing is to apply the air box in the right way.



In order to avoid upstream restrictions, it should be sited at the point at which the induction pulse can expand in the same way as if there were no box there at all, i.e. the bell mouths should be allowed to protrude into the box with adequate clearances and the measurement "A" should be at least as great as the carburettor bore size.

Tubular couplings as seen here will effectively increase the tuned ram length to an RPM level that will probably be too low.



RAM LENGTH is effectively the tuned length from the inlet valve head or piston port face, to the end of the intake trumpet.

At the moment that the valve or port first starts to open, a pressure wave starts to travel back and forth through the inlet tract, changing from plus pressure to minus pressure, or effective suction. If the wave front is caught at the right moment, it can be used to help ram mixture into the engine, thus inducing a form of mild supercharging. You can calculate approximate correct ram length using the formula below, where L = length.

For a four-stroke:

$$L \text{ in ins} = \frac{228 \times T}{N} \qquad \text{in mms} = \frac{5791 \times T}{N}$$

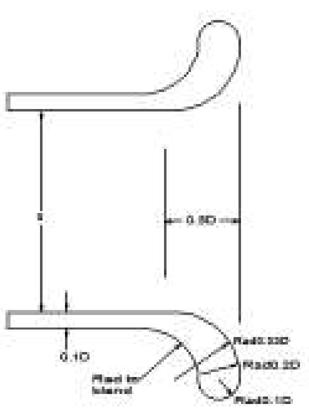
Where T = Total intake valve duration in degrees
N = The estimated RPM at which max. power is required, minus five hundred

And for a two-stroke:

$$L \text{ in ins} = \frac{1150 \times T}{N} \qquad \text{in mms} = \frac{29210 \times T}{N}$$

Where T = Inlet port opening in degrees
N = The estimated RPM at which max. power will be achieved.

The two-stroke calculation will result in a length that is too great to be practical and may be divided by 3 or 5 to fit installation requirements.



Ram pipes or trumpets should have fully round ends.

Contrary to general belief, much of the intake air is drawn in around the edges of the mouth and, if there are sharp edges in this area, flow will be interrupted and turbulence will cause restriction in the bell mouth.
This is also the reason why bell mouths should be allowed to protrude into the air box rather than finish flush with the wall.
The position of the air entry to the box is not critical provided it is not within 50mms or so, of the bell mouths.

CARBURETTORS.

In order to increase power the process of improving volumetric efficiency is invariably tied up with an increase in the operating RPM. However, if we increase RPM, then we will inevitably be increasing the air speed in the inlet tract, which includes the carburettor.
The size of carburettor that is normally suitable for the standard engine is rarely large enough for any appreciable increase in the state of tune other than stage 1.
Stage 1 modifications can vary from one engine to another but generally comprise a mild increase in cam profile on a four-stroke or lengthening of inlet and exhaust timings by about 5 degrees on a two- stroke, raising compression by about one ratio, smoothing out porting and possibly fitting a high performance exhaust system.
Even at this level the engine can easily be strangled by its standard carburetion. So any further increase means that we are inevitably faced with the need to up rate the carburetion.

To evaluate the European options available, we will first divide them into two types depending on their principles of operation:

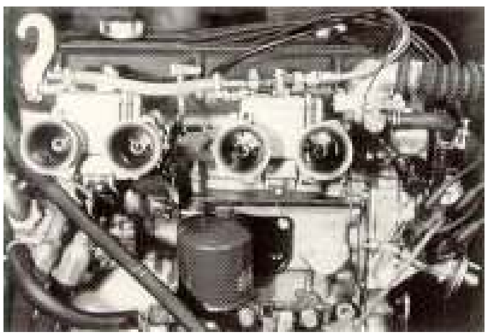
Fixed choke, butterfly air control.
Weber and Dellorto

Other fixed choke carburettors are available but are impractical due to lack of adjustable features.
Variable choke, butterfly air control, constant depression (CD) S.U., Stromberg C.D., Mikuni.
Variable choke, manual slide control of air and fuel. Amal, Bing, Keihin, Mikuni, Dellorto.

Suitability and convenience of application:

1. Weber D.C.O.E. series side draught
I.D.A. and D.C.N series downdraught
Size range from 38mm to 48mm.

Without doubt the best high performance carburettor available in the world for application in cars.



Wide range chokes and jets readily available for applying to any engine.
The sealed throttle spindles make them particularly suitable for up- stream supercharging.
Usable for motorcycles but rather big and bulky for average application, also needs special fuel delivery requirements, i.e. pump delivery or modified needle valves.

2. Dellorto D.H.L.A. series sidedraught
F.Z.D. series sidedraught
Size range from 20mm to 48mm
D.H.L.A. series similar to Weber D.C.O.E. but not quite as efficient in terms of air flow.
Not quite the same range of variables available.
Other series are readily adaptable to motorcycle applications.

3. S.U. - Size range from one and a quarter to two inch .
The most widely used performance carburettor up to the late 70s.
Very popular for road conversions. Very adaptable with wide range of tuning needles available.
Tend to suffer fuel surge on high cornering G-forces.

4. STROMBERG C.D. - Size and range from one and a quarter to one and three quarters of an inch.
Similar in operation to S.U. Not such a wide range of needles, application not quite so simple.

5. MIKUNI & KEIHIN - Both make C.D. carburettors for use on road bikes and also make manual slide control versions for use on racing bikes.
They are available as kits for some production models but generally, they are difficult to apply to other models due to the lack of non-standard jets and needles.
Properly set up, they make efficient and reliable racing carburetion.

6. AMAL - size range 25mm - 42mm
The most popular and successful motorcycle carburettor over many years.
Very adaptable to almost any engine and very forgiving to slight errors in tuning.

All carburettors, whatever the make, suffer, to a degree, from two major faults...
Fuel frothing due to vibration and float chamber fuel surge due to cornering G-forces.
In many cases these can be minimised by careful attention to flexible mountings, float levels, needle valves and springs where applicable.

CARBURETTOR SELECTION

Refer to the Staging table in the camshaft section of the manual for Stage descriptions.

Stage 1. There is no real point in modifying even slightly if the standard engine is not of the GT type, which is really the manufacturer's first mild production tuning step from his basic engine. Carburetion at this stage will generally be two small C.D.'s or a single progressive twin-choke which will only require needle or jet changes for Stage 1.

Stage 2. Increase in volumetric efficiency at this point will call for an increase in size of C.D. carbs. e.g. 1300cc engine running on 2 x 1.25 inch S.U.s will need to move up to 1.5 inch units. Or will need a large choke version of twin-choke DD carb.). Also will need a change of air cleaners to free-flow type. At this stage single choke injection systems can be considered as a possible alternative.

Stage 3. Further volumetric efficiency improvements now create a "grey area" in which well-engineered twin carbs, or single choke injection, will still do the required job, but the move toward one choke per cylinder must be seriously considered. Cylinder sizes up to 400 cc will require a 40mm carburettor with 30 to 34 mm chokes fitted e.g. Ford 2000cc four cylinder will need 2 x 48DCOE Weber or DHLA Dellorto.

Stage 4. One choke per cylinder is now essential to fully justify other engine modifications. Available choices are Weber DCOE, Dellorto DHLA, Amal, Keihin or Mikuni smooth bores. Carburettor sizes will need to be as follows for various cylinder sizes:
250cc 40mm with 32-34mm choke or injection bore.
400cc 45mm with 36-40mm choke or injection bore.
500cc 48-52 with 40-46mm choke or injection bore.

Stage 5/6 As above except that we now move into the area where individual engine build specifications will dictate precise intake breathing requirements, and it is no longer possible to predict general sizes.

Only dynamometer testing of the engine build combinations will produce the most effective results from carburetion or injection variants.
At best, initial carburetion choice can only be a compromise generally suited to the user's overall requirements and will eventually have to be adjusted accordingly.
Genuine designers and suppliers of good high performance equipment will be able to advise you on jet settings for your individual needs.
Beware of buying cheap unrelated tuning parts; nobody will be prepared to advise you on the tuning details needed to complete a satisfactory job.

FUEL INJECTION, THE ALTERNATIVE

The term "fuel-injection" should really only describe the process of injection directly into the combustion chamber, in the same way that a diesel engine functions.
The last petrol engine of any note to do this, was the Mercedes 300SL and generally, the design was discarded due to impracticality and high cost. That engine also used desmodromic valve gear, but more of that later.
However, direct injection has recently been introduced in a small range of modern cars.

Generally, present day injection systems squirt fuel into the inlet manifold or cylinder head close to the inlet valve. They are really just another form of carburetion, classified under the expression "pressurised fuel metering systems", and of course, are now all controlled by microprocessor engine management systems.

All injection systems work on the same basic principle. A series of signals from the engine are monitored and used to produce a squirt of fuel of the correct size at the correct time. The important signals that need to be measured are:

1. Engine speed - sensed electronically by a transducer on the crankshaft.
2. Throttle position - measured electronically and indicating the driver's power call-off from the engine at any time, e.g. the sudden change from one eighth open to full open indicates driver requirement for sudden acceleration and therefore mixture richness is fed in accordingly.
3. Engine air consumption or volumetric efficiency. A big thorn in the side of injection equipment designers. Measured electronically now, but on earlier systems, measured mechanically by use of manifold pressure sensing devices or by a 'floating' air bell in the induction tract. This is very sensitive but can be subject to problems of dirt deposits causing 'sticky' operation. It is also difficult to modify when the engine is up rated because it is critical in design and in itself offers an obstruction to clean airflow.

Various other controls are introduced depending on the sophistication of the system or the individual requirements of the manufacturer. Such devices as atmospheric pressure, temperature and exhaust gas analysis sensors, feed signals to a microprocessor, which in turn, digitally instructs the metering system to correct the fuel flow accordingly.

But, regardless of the level of the additional sophistication, all systems have to work around the three basic control parameters listed above.
Most injection systems are purpose-designed for the vehicle to which they are fitted and are difficult to re-adapt for other engines.

Systems used on formula 1 and 2 cars are available in component form to be used on any engine, but the responsibility for adapting and fitting, include determination of the computer control software to suit fuel requirements lies with the customer, a formidable task for anyone who does not have expensive test equipment.
Bosch were far and away the world leaders in supply of electronic fuel injection systems or technology licensing, but an increasing number of other manufacturers are now offering alternatives, many based on the Bosch technology.

Although their then "state of the art" systems, fitted to high performance market leaders like B.M.W. and Mercedes were based on the fully electronic "L" system, other then current models like the 4/4 Ford Sierra, still used the out of date mechanical "K" system, though at the expense of poor fuel consumption and high emission levels and maintenance costs.

Carburettor manufacturers Weber, started to offer retro-fit fuel injection system, programmably adjustable with a PC desktop computer, and incorporating an electronic ignition system controlled from the same processor.

A low-cost alternative system designed to be fitted at manufacturing stage, was developed in the Piper workshops over a period of a few years, and was made available as an electronic multi-point carburetion system for high volume production vehicles.

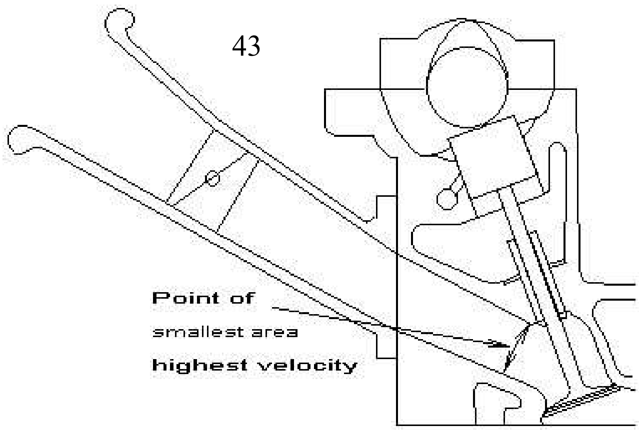
The table below lists the variations of driving conditions and the resulting demands put on any fuel metering system, whether carburetion or injection.

Driving Condition	Throttle Position	Engine Speed	Volumetric Efficiency	Fuel Requirement
Cold start	Closed to 15%	Low	Poor	Rich
Hot start	15%	Low	Poor	Weak
Cruise at 70 motorway flat or downhill	20%	Med/high	Poor	Weak
Flat out flat road	100%	High	Good	Med.
Accelerate on steep hill	50 - 100%	Low	Poor	Med.
Dragster start from lights	100%	Low	Poor	Rich
Cruise at 70 slight uphill	60%	Med	Med	Med.
Shut throttle suddenly from 150 mph	Closed	High	Poor	Near zero

The difficulty of meeting all these possible combinations makes the carburettor look good value for money and it is.
However the requirements of greater economy, together with reduced exhaust emission levels, were necessitating the change to a much greater level of sophistication in carburettor design and were inevitably leading us into the era of electronic carburetion.
In racing, this had been the case since the early seventies.

Further discussion of electronic fuel systems may be found in the section on electronic engine management.

INLET PORTS AND VALVES



The transition of the manifold from the carburettor or injection air control body to the port and valve should be as a gradually reducing cross-sectional area from the bell mouth at the atmospheric end of the tract, right through to the intake valve head (Fig. 43), in order to ensure that efficient maximum gas velocity is achieved.

This is around 400ft/sec. (122 metres/sec.) and should be achieved as close to the valve as possible.

In the case of the four-stroke, this will be just upstream of the valve guide boss where the port must start opening out to reduce velocities in the throat and around the valve head.

For the two-stroke, maximum velocity can occur at the piston skirt face.
Having calculated the correct minimum throat diameter, the intake tract should progressively converge to that size from the bell mouth, at a rate of approximately 4mms in 100, (4%) or an included angle of 2-3 degs.

This taper in the intake tract is to compensate for the gas drag that occurs in any flow system, and that would otherwise tend to restrict the effective cross-sectional area.

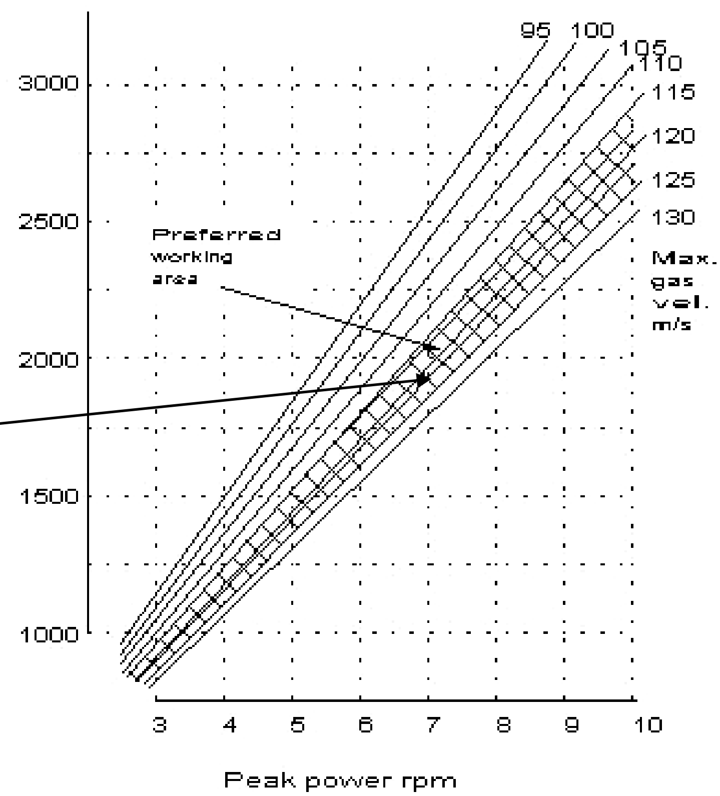
Minimum intake throat diameter, related to cylinder capacity and RPM.

Sq Mms/Litre/Cylinder

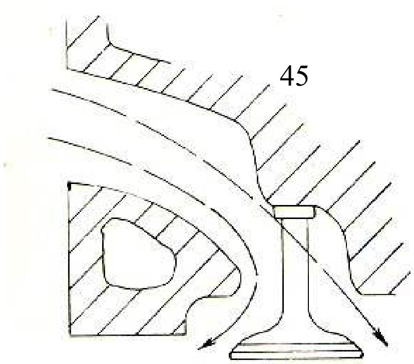
1 sq. in. = 645 sq. mms

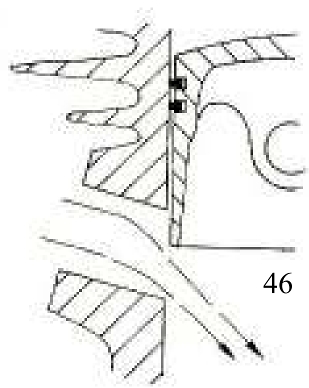
So if you have a 500cc cylinder capacity and the engine is tuned to produce max. power at
7000 rpm, then the minimum port section at
the throat should be
1800/2 = 900 sq. mms.
= 1.39 sq. ins.

1.4 sq. ins. area = 1.33 ins. dia.



When we refer to the valve, we mean of course the poppet valve in the four-stroke engine as opposed to the sleeve valve, long ago discarded in four-stroke engines, but still retained by the two-stroke in the form of the piston skirt opening and closing the cylinder ports.
It is a great pity that the efficient flow characteristics of the poppet valve are denied the two-stroke, due to the difficulty of driving them at crankshaft speed.

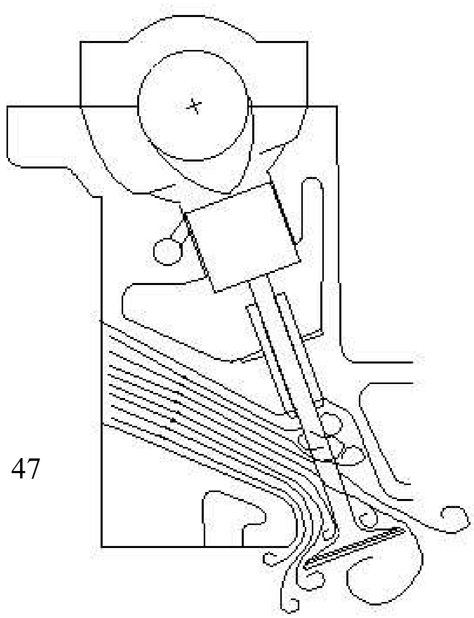




Nevertheless, the facts are unavoidable: a well designed inlet port and valve (Fig. 45) achieves a discharge coefficient approaching 100%, whilst the sleeve valve of the two-stroke (Fig. 46) only reaches about 80% at its most efficient.

The discharge coefficient is the ratio of the amount of gas that will pass, compared to its size.

There are many publications illustrating the detailed cylinder head modifications that should be carried out on specific models of engine, so I do not intend to waste time and space by re - covering old ground here.
However, there are some vital signs and rules that should be observed, regardless of the hardware that is being worked on.



Gas flow within the intake system, particularly around the valve head and stem, is highly complex and almost impossible to visually depict other than in an animated diagram.

Every irregularity in the flow path causes vortex shedding to occur (Fig. 47), which effectively reduces the efficiency of the system.
Vortex shedding is the effect of tiny swirls of gas being generated at every sudden change of direction or size.

When re-working an intake system, the simplest approach is to imagine yourself as the slug of intake gas, moving along the tract.

Each obstruction or change of section that would upset or irritate your path will be equally disturbing to the inlet charge flow.

All inlet tract joints should be accurately matched, i.e. carb to manifold and manifold to port, including gaskets.
Every stepped joint will cause turbulence in the stream and will sap valuable energy from the ingoing charge.

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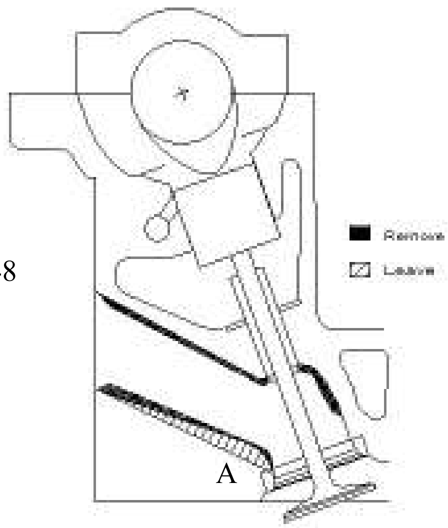

Fig.48 Intake port contouring

All corners should be radiussed to remove potential flow interruption, but not at the cost of removing too much metal and losing the correct shape for example, in (Fig. 48) careless removal of metal at "A" will result in a port flow that is so bad it would have been better left as standard.
The black area shows the correct modification.

Inlet valve guide bosses can be smoothed and streamlined but the valve stem is unalterably round and will eventually control the turbulent pattern in the throat.

In some ports there is a case for removing the inlet guide and boss right back to the port wall, providing there is sufficient guide length left to fully support the valve and hold it square on the seat.
Areas adjacent to the inlet valve seat should be radiussed to create a smooth blend from port wall to valve seat and from seat to combustion chamber roof. Careful attention in this area alone can raise the flow coefficient by over 10%.
Similarly, the shape of the valve head is of great importance and, although true individual valve head shape can only be determined by knowing the characteristic of the port, as a general rule of thumb, "flat" approach ports, as used in Mini A-series engines work best with "penny on a stick" valve heads, while downdraught ports give best flow with a "tulip" or spherically backed valve head.
Highly developed racing engines invariably have steeply down-draughted intake ports to assist the inlet flow across the valve head.

Although the general design for these engines is the pent-roofed, four valve layout, the Yamaha FZ750 used 5 valves per cylinder and had even experimented with seven valves, in the interests of improving the intake flow process.

Two-stroke inlet valves.
Two-stroke piston skirts can be re-worked to ensure that they fully clear the top of the port and, if it has any downdraughting, should be chamfered to match.
Although the sharp edges can be broken to assist flow at small openings, radiussing should not be carried out because this will make the port timing unstable.

Inlet valve timing.

Four-stroke.
Average production engine timing duration is from 240 to 260 degrees, with opening points varying from 5 degrees to 25 degrees before T.D.C. and closing from 40 degrees to 55 degrees after B.D.C.
Valve lifts range from 8.0mm for a 250cc cylinder to 10.0mm for a 500cc cylinder. These engines will be giving about 60 Bhp/L and produce maximum power between 5200 and 5800 rpm.

If we increase the level of tune in "stages", then these characteristics will alter as indicated in the chart below.

Stage	Application	Inlet V Timing BTDC	ATDC	Valve lift (mms) 250cyl	500cyl	Potential Bhp/L
Std.	Std. Saloon	20	50	7.0	10.0	50
St 1	Improved std.	30	60	9.0	10.5	62
St 2	Rally M/cross Grasstrack	40	70	9.5	11.0	80
St 3	Race 1	50	80	10.0	11.5	95
	Race 2	58	88	10.0	11.5	105
SPL	Super/ch Drag	62	92	10.0	12.0	150
SPL	Turbo/ch Race	45	85	10.0	12.5	150

Specially developed racing four-strokes running high boost pressures, and ultra-high revving two-strokes will develop in excess of 200 Bhp/L.

TWO - STROKE PORT TIMING

Because the piston uncovers the ports equally on it’s up and down strokes, it has symmetrical timing unless disc or other forms of rotary valve timing control are added.

These methods of control invariably increase the cost and complexity of the engine, which is a pity because the two-stroke does respond to asymmetric changes in inlet timing.

Whilst, in general, slight changes in inlet opening do not give power improvements, the same changes in inlet closing certainly do. Therefore, while it is necessary to lengthen inlet timing to increase power and rpm, the low speed power losses are enormous, hence the need for a lot of gear ratios.

This effect can be offset slightly by the use of reed valves in a piston ported engine, but, whilst they increase low and mid-range power, they lose a certain amount of top end power due to the flow restriction and the fact that, even though the reed is very light, it still has inertia which has to be overcome by the inlet stream. This in turn means that the small amount of energy required to move the reeds must be taken from the inlet stream which therefore loses some of it's high speed ram effect.

Previous reference has been made to the fact that the loop/scavenge or conventional crankcase induction two-stroke is really a supercharged engine because it sucks the gas into the crankcase and then blows it into the combustion chamber.

Why, therefore, doesn't it produce as much power as an externally supercharged engine?

The reason is that the petrol/air mixture is fouled, either by its own intrinsic oil content or by being exposed to injected hot oil being sprayed around the crankcase.

It is also pre-heated by thermal transfer, from the surrounding hot components, further heated by compression through the transfer ports before being subjected to combustion.

All this means that the combustion process is not as efficient as a four-stroke but, because it happens twice as often, it can still produce good power.

Approximate changes in staged tuning of the inlet are shown in this table.

Application	Inlet duration Open BTDC	Close ATDC	RPM at max. power	Potential BHP/L
Std Street	70	70	7000	80-90

Stage 1	78	78	8500	100-120
Stage 2	90	90	12000	150-250

51 *Piston-valved racing Yamaha.*

The choice between piston-valved and disc-valved two-stroke racing engines is still argued out and successful machinery is divided into both categories.

The successful Yamaha's (Fig. 51) retained piston valves as did most of the motocross bikes (Fig. 52), but tended to combine reed valves as well.

On the other hand the RG 500 Suzuki and KH250 Kawasaki (Fig. 53), got their results using rotary disc valves.

52 *2-stroke, piston valved, motocrosser: Suzuki RM80.*

53 *Disc-valved Kawasaki 2-stroke racing KH250.*