**Note 34**

## Optimum gas velocity at inlet

The reason why an optimum gas velocity occurs in the inlet flow of a liquid-fuelled four-stroke piston engine was explained by L Mantell in the '30s (294, p 82) as follows:-

> 'To *return ... to the inlet valve functioning as a disintegratory agent"* *(of the liquid fuel)* *"..., while making this big enough to pass a quantum of live charge, it must on the other hand be small enough to speed up the charge locally and so put the final finishing touch on the so-called atomisation of the fuel. This valve, therefore, has a critical size like the choke; <u>too big a valve may cause a loss of power just as an undersized valve will</u> (DST underlining) – in the former case the final state of the fuel in the head will be too coarse to effect a sufficiently complete evaporation and admixture with the oxygen. The result will be that all the large particles of (fuel) will burn too slowly to have their full driving effect ...* "

This descriptive approach is, in effect, pointing out that, in choosing inlet valve size, both 'breathing' and 'burning' have to be considered, ie what matters is maximising the product of Volumetric Efficiency (EV) x Combustion Efficiency (EC).

Inlet pressure loss rises as $(\text{velocity})^2$ and, regarding the effect on EC, C. F. and E. S. Taylor (594) published in 1938 tests which, by varying inlet port sizes at constant RPM, showed that flame speed rose linearly with inlet velocity. This illustrated the effect of in-cylinder turbulence as well as the better fuel air mixing referred to by Mantell.

It is apparent from the above that the optimum value of Mean Gas Velocity (MGV) at inlet will depend on:-

- The 'drag coefficient' of the inlet system (higher drag will lower the value). Up to 1952 all CoY engines had 'Tortuous' high-drag systems, and afterwards all had 'Individual, Tuned' systems of low drag (at resonant speed);
- The degree to which the fuel is 'atomised' by the method of supply, eg carburettor or injection (inlet or in-cylinder) or whether a supercharger is fitted which vaporises the fuel by its heat of compression and 'mashes' it mechanically in the rotor(s) (more 'atomisation' or evaporation pre-valve will also lower the value).
- The type of fuel (easy or hard to vaporise -the latter will raise the value).

MGV as a valuable guide to efficient engine design was probably first pointed out by Laurence Pomeroy Senior when Chief Engineer of Vauxhall around 1910. Ricardo has reported (343) that Pomeroy at that date *"contended that piston speed was limited only by breathing capacity and that (there was) ... no reason ... why piston speeds up to 2500 ft/min (12.7 m/s) should not be obtainable with a single row of valves and ... 3000 ft/min (15.2 m/s) or even over if a double row be employed.* "Pomeroy at that date was racing side valve engines, but would have known of Continental overhead valve (OHV) designs, especially, perhaps, the 1909 Fiat S61 engine with four vertical valves. If it is assumed that his comments applied to such OHV heads, with vertical valves contained within the cylinder bore, then it can be deduced that he was calculating from an optimum MGV around 200ft/sec (61 m/s) (based on valve <u>head</u> area, which has been standardised for this review because it is the figure most often available. Caution is needed on some early data where 'valve diameter' really means 'port diameter' and adjustment is needed. MGV is calculated from MPS with the standard assumption of incompressible flow). This MGV would have been for a 'Tortuous' inlet system, four cylinders drawing from one updraught carburettor.

Ricardo around 1918 took up Pomeroy's view that MGV was a critical factor in determining performance. In his later *High Speed Engine* (242) he published a generalised curve of EV v. MGV from which it can be deduced that Maximum Indicated Power per unit of inlet valve area, which is proportional to (EV x MGV) would occur at MGV = 250 ft/sec (76 m/s). Again, this would be supposing a 'Tortuous' inlet system and, with decreasing Mechanical Efficiency (EM) with rising RPM, the Maximum Brake Power would be at lower MGV. However, this result took no account of the effect of velocity on EC. Ricardo's 1922 IL4 3L racing design for Vauxhall, which bettered his general EV v MGV curve at the top end, and which, of course, integrated the velocity effects, peaked in BHP at MGV = 173 ft/sec (52.7 m/s). Although this had a dual-throat carburettor feeding cylinders 1,4 and 2,3, the approach to this was (a) very Tortuous and (b) warmed, by passage through the crankcase.

Mantell's deduction of the mid '30s has been quoted already. He gave no valve-related velocity but proposed an inlet peak value of 180 ft/sec (54.9 m/s) and a carburettor choke figure of 300 ft/sec (91.4 m/s).

Shortly after WW2 a statistical analysis of various aero engines was published in the USA (783), which gave the relation:-

$$A \quad 0.025 \cdot \frac{(VN)}{(2000)} \text{ sq in}$$

where A — Inlet area based on the inner valve-seat diameter (neglecting the valve stem)

V — Swept Volume - cu in

N — RPM

This result, which applied to NA and PC units with B/S between 1.12 to 0.79, can be reduced to:-

MGV = 180ft/sec (55 m/s)

The inlet conditions would be 'Tortuous'.

Harry Mundy in 1957 (52) proposed an inlet port area ratio equivalent to IVA/PA = 0.33 for the Individual, Tuned case, ie at MPS = 4000 ft/min (20.3 m/s) which he then recommended as the mechanical limit, MGV = 202 ft/sec (61.6 m/s). At a piston speed typical of 1990 onwards, ie 5000 ft/min (25.4 m/s) MGV rises to 253 ft/sec (77 m/s).

C. F. Taylor in 1968 (784) modified the inlet velocity concept by introducing the valve coefficient of discharge to obtain the actual velocity from the nominal average and then related it to the speed of sound as a Mach Number (labelled Z). This, as for Ricardo and Mundy, did not introduce the effect of velocity on EC. The Z = 0.58 proposed for a racing engine with Individual, Tuned tracts and methanol fuel (cooling the charge and lowering the speed of sound) was equivalent to MGV = 70 m/s (Vol 2, p400). The compressible flow parameter (Mass Flow x -√(Temperature)/(Area x Pressure) at 58% of the speed of sound is 82% of the choking figure (429).

Finally, a practical case is known where the late Brian Lovell put to good use the general theory of an optimum inlet velocity. Newly arrived at Weslake's in the late '60s, he was asked to look at a 500cc twin which had given disappointing power. With specialist carburettor experience at Zenith, where the design guide was 'Optimum Mixing Velocity', he decided that the engine ports, sized to give 'Minimum Pressure Drop', were too large. Despite scepticism, they were reduced and a large power increase was obtained (782).

## Statistics 1906-1998

The attached figures below on page 4, 111/DST and 112/DST, show I V A / P A and MGVP (MGV at Peak Power) for CoY engines over the years. This suggests that the best designers understood in the years of Tortuous inlet tracts, and usually with superchargers, that MGVP around 55 m/s was the value to aim at. When Individual, Tuned systems, normally-aspirated came into use, 1952 onwards, designers felt their way to about 75 m/s noting that inlet fuel injection came in 1962. The particularly low values for 1954-55 are those of the Mercedes M196, which had in-cylinder injection spraying partially onto the exhaust valve. With this process supplying all the necessary 'atomisation' of the methanol-base fuel, the inlet system could be sized to give 'minimum pressure drop' and raise EV without spoiling EC (at least not on account of insufficient flow speed through the valve – there were other spoilers in the M196, see the Design Era text, Egs 32 and 33).

The turbocharged engines of 1982-1988 did show lower values of MGVP, which is in accordance with the theory that the heat of compression, though largely removed by intercooling, provided some of the needful fuel/air mixing.

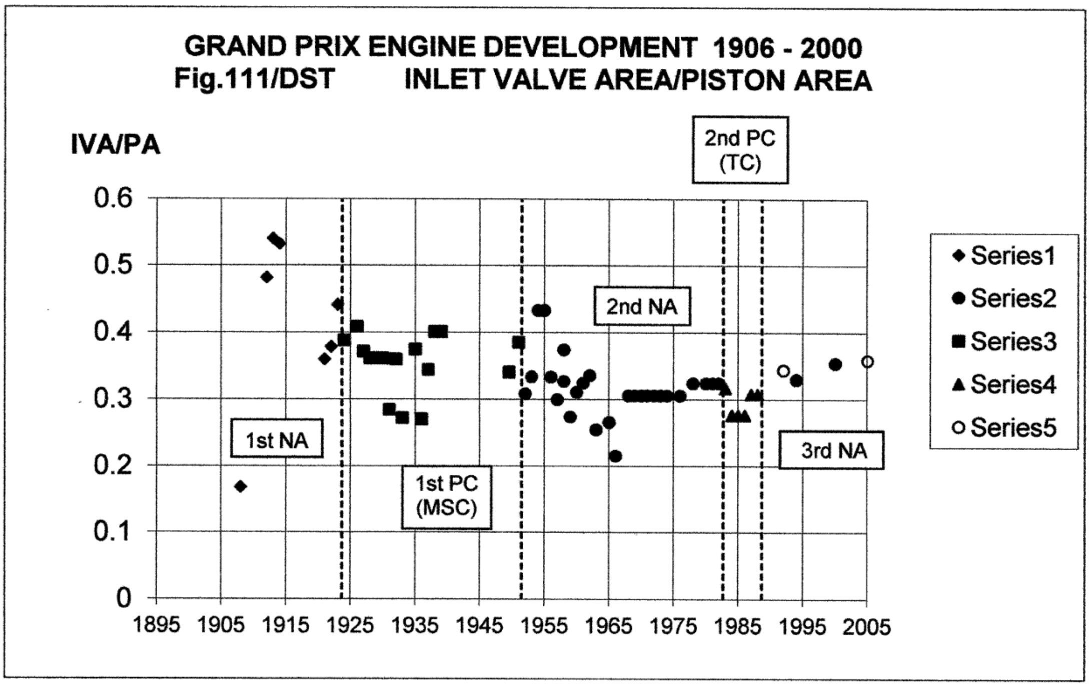
## P.S.on Direct Petrol Injection (DPI)

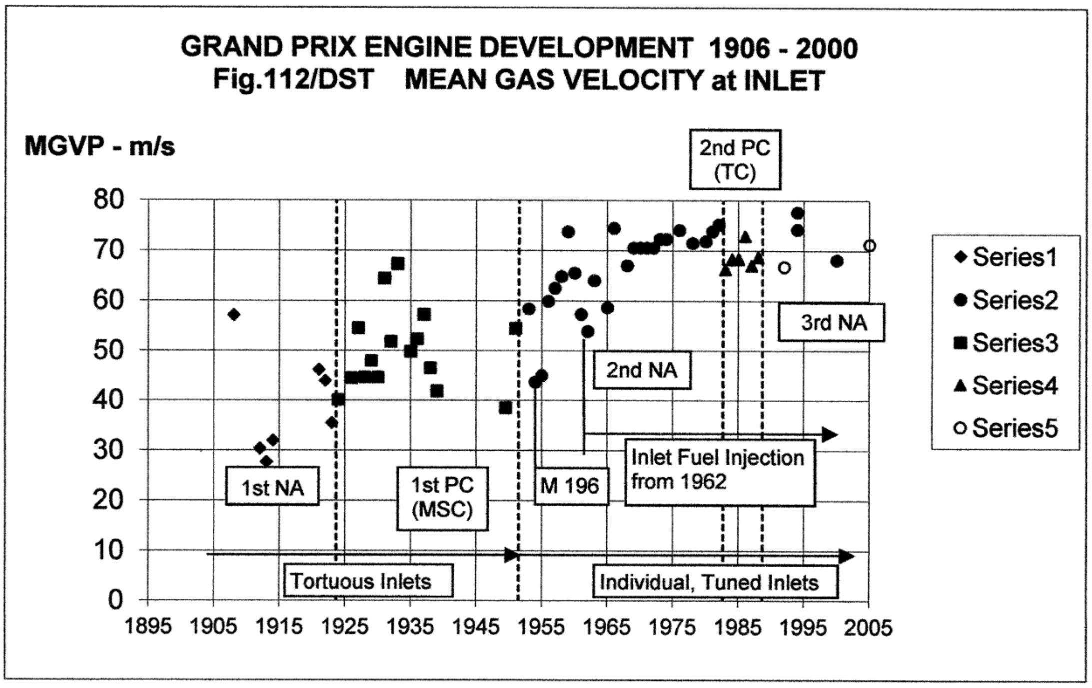
November 2013.

The point on P.1 about atomization of fuel is relevant to the 2014 rules which require Direct Petrol Injection (DPI) into the cylinder and allow a 500 Bar pressure for this system. This contrasts with only *7 Bar* in the 1967 Cosworth DFV Lucas *port* injection.

If this ultra-high-pressure DPI system can provide all the necessary preparation of the fuel/air mixture to obtain maximum Combustion Efficiency (EC) then there is no longer a need to compromise the inlet port and valve regarding velocity or the creation of swirl. They can be sized and shaped for maximum Volumetric Efficiency (EV).

Page 4 continues below


GRAND PRIX ENGINE DEVELOPMENT 1906 - 2000
Fig.111/DST INLET VALVE AREA/PISTON AREA
IVA/PA
2nd PC
(TC)
2nd NA
1st NA
1st PC
(MSC)
3rd NA
0.6
0.5
0.4
0.3
0.2
0.1
0
1895 1905 1915 1925 1935 1945 1955 1965 1975 1985 1995 2005
Series1
Series2
Series3
Series4
Series5


GRAND PRIX ENGINE DEVELOPMENT 1906 - 2000
Fig.112/DST MEAN GAS VELOCITY at INLET
MGVP - m/s
2nd PC
(TC)
3rd NA
2nd NA
Inlet Fuel Injection
from 1962
1st NA
1st PC
(MSC)
M 196
Tortuous Inlets
Individual, Tuned Inlets
80
70
60
50
40
30
20
10
0
1895 1905 1915 1925 1935 1945 1955 1965 1975 1985 1995 2005
Series1
Series2
Series3
Series4
Series5