Note 23

Fuel, Combustion Chambers and Compression Ratio

Early engines

Gottlieb Daimler's Maybach-designed 1st engine for automotive use in 1885 had a Compression Ratio (R) of about 2.4. This was with a combustion chamber extending beyond the side of the cylinder to accommodate a side exhaust valve and suction-operated overhead inlet valve. The 1895 Panhard with a similar chamber layout, also Maybach designed, was about R = 3 (2).

By 1906 the side-valve Renault French Grand Prix winner (Eg. 1) had R = 4. Petrol at that date, by the grading system created by Edgar in 1927 applied retrospectively, was about 45 or 50 Octane Number (ON) (apparently equivalent to the later "Motor Method" ON, see Note 58-2).It is noteworthy that in their contemporaneous writings on engines neither Frederick Lanchester nor Dugald Clark mentioned compression ratio, as though expecting it to remain at the levels then current.

However, by the movement in 1907 to more compact over-head-valve combustion chambers, it was possible in the years just before WW1 for R to reach about 5½; in 1914 for the Mercedes French Grand Prix winner (Eg. 6) fuel was improved by mixing 50% Benzole with 50% petrol (468).

Ricardo's fuel discoveries

During the latter part of WW1 Harry Ricardo discovered that petrol refined from Borneo crude oil could add a unit to the value of R typical with the then-best standard (probably Persian-oil-based) fuel. The 1st non-stop direct Atlantic crossing by air in 1919 was with the Rolls-Royce *Eagle* engines taking advantage of this better petrol to reduce fuel consumption (343).

Post-WW1 GP engines took advantage also of better fuel as well as Al-alloy pistons and smaller bores and the 1922 FIAT IL6 2L (Eg.8), with a near-hemispherical 2-valve combustion chamber, reached R = 7. The 1923 Sunbeam (Eg. 9), closely derived from the FIAT, had R = 7.4 (Note 32 discusses the post French GP strip condition of this engine).
This was the last CoY to burn plain petrol without additives.

Meanwhile Ricardo had also pioneered the use of Ethyl-Alcohol-base fuel which not-only enabled R to be raised over the best petrol but, by cooling the inlet charge much more than petrol by its greater latent heat of evaporation, produced a greater mass of air inhaled. Thus power was increased in two ways *but* Specific Fuel Consumption was doubled. This new "RD" (Ricardo-Distillers) fuel was used in the early '20s only for short-distance Brooklands races and hill-climb specials, e.g. Raymond Mays' Bugattis especially (446), probably because in such events the extra fuel consumption did not matter.

Alcohol-base fuel in Grand Prix racing

When Pressure-Charging (PC) was adopted generally after 1923, alcohol-base fuel was soon accepted as the way to avoid detonation by cooling the compressed charge. The value of R was restricted for the next 27 years to between 6 and 7 while Inlet Valve Pressure (IVP) rose from 1.5 to 3.9 ATA and the mixtures grew steadily richer in alcohol. Petrol and Benzole, the other major constituents of racing fuel, were steadily reduced (see Appendix 2) and the fuel/air ratio also grew richer relative to stoichiometric (chemically-correct) ratio. Racing miles-per-gallon therefore fell steadily and two replenishment stops were needed in 500 km by 1951.

Alcohol –base fuel remained the staple diet after the end of the 1st PC Era, into the 2nd NA Era, from 1952 to 1957 with R from 12 to 13. Nitro-Methane, an oxygen-bearing liquid, made its appearance as a fuel additive towards the end of these years.

The change to petrol

The companies who supplied free fuel for racing then forced a change to the rules to require "Pump petrol" with the aim of improving their advertising link from GP winners to "the petrol the ordinary motorist can buy!". However, difficulty at first in choosing an international standard

led to the specification of Genera Aviation petrol of 100/130 grade (see Note 58-2) for 1958 to 1960. Of course, this was *nothing* like petrol on sale to motorists!
Useable R was nearly as high as on Alcohol but the evaporative cooling gain was lost, e.g. the 1958 Vanwall had R = 11.5 and power output was down (after unrelated improvements) by about 4% (68).

Squish and Swirl

"Squish" and "Swirl" were both factors in obtaining high values of R in the Vanwall as direct contributions from its origin in the 1952 Norton motorcycle racing engine. "Axial Swirl" of the inlet charge inside the cylinder was induced by curving the port in the plane of the bore. The rising piston then compressed the swirl into the smaller diameter of the combustion chamber and so accelerated its angular velocity by conservation of momentum. This method of creating turbulence favourable to burning was originated by Harry Weslake in 1948. "Squish" resulted from local areas of close clearance at TDC in the chamber causing ejection of a turbulent charge flow towards the sparking plug. This had been patented by Harry Ricardo in 1919 to raise side-valve compression ratio and it had given 3 decades of new life to that cheap type, but he had not used it in his famous DOHC 1922 Vauxhall TT engine (see SO8 in Appendix 1). It is believed it was first used in an OHV engine by Leo Kuzmicki for the 1951 Norton 350 cc racing machine, with substantial benefit (683)(see **Sub-Note A**). It has been suggested that Gioachino Colombo adopted Squish in his improvements to the 1952 Maserati 2L engine; if so, Note 57 shows that this was *not* carried over to the 1954 250F 2.5L type, although ref. (32) has a sketch of such an arrangement (which clearly is *not* from parts seen).

After 1960 the then-top-quality of pump petrol at 102 Research Octane Number (RON) was specified by rule and this Octane rating has remained unchanged since, although with a steady tightening of the specification after mid-1992 to eliminate power-boosting constituents (see Appendix 2 and Note 90).

Keith Duckworth and Barrel Turbulence

Keith Duckworth in his 1965-designed Cosworth type FVA engine and later types, including of course his famous DFV, introduced an inlet port non-orthogonal to the valve head to promote *deliberately* "Barrel Turbulence" in the plane of crankshaft rotation for the same purpose as Axial Swirl but more effectively (see Note 80 and also "The Unique Cosworth Story"). [This in-cylinder motion is also called "Tumble Swirl" and sometimes the axial variety is simply called "swirl" and the crank plane version "tumble".] It is posible that some previous engines with side-draught ports had some tumble *accidentally.*

Duckworth used a narrower valve included angle (VIA = 40'^{0}, reduced to 32^{0}) in his re-use of 4-valve-per-cylinder architecture to assist his barrel turbulence and to produce a compact combustion chamber with a flat piston top having squish plateaux and no hump to sub-divide the charge, plus the advantage of a central sparking plug.

Pressure-Charging and Toluene

With TurboCharging (TC) during 1983 – 1988 Toluene-base fuel was developed specifically to meet the *petrol* RON102 regulation test in low-speed laboratory engines but then give superior knock-resistance in high-speed racing engines (see Note 90). During this era R around 7½ was typical when maximum IVP and power were sought but rising to 9.4 in the 1988 Honda (Eg. 71) as IVP was restricted and race fuel quantity diminished (20).

Tighter fuel control from mid-1992

The chemical competition – which had made nonsense of the 1957 fuel companies cry of "petrol the same as you can buy" – continued into the post-1988 3rd Naturally-Aspirated Era (535) until, in 1992, Honda in the RA122E/B (SO20 in Appendix 1) were using R = 12.9 with a Bore of 88 mm and B/S = 1.84 (69). As mentioned, half-way through that season the rule-making authorities had had enough of it and a tighter control was instituted to try to return racing fuel to "real petrol". This cost the Honda 5% of power (69).

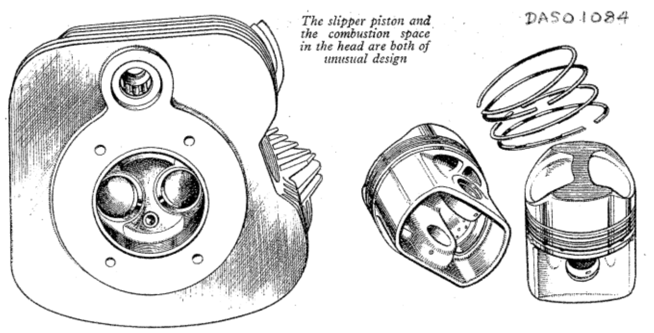
The last official figure for R for a GP engine in the review period was 12 in the 2000 Ferrari 049 (Eg. 85) with a bore of 96 mm and B/S = 2.32. Piston-crown cut-outs are of course required to permit all valves open at exhaust TDC. With tight-clearance squish plateaux this ratio also requires for reliability computerised stressing to calculate component elastic deflections and temperature differential expansions plus computer-controlled machining plus electronic engine-clutch-gearbox management (EMS) to avoid over-revving. The EMS and knock sensors are also needed to retard the ignition to avoid detonation at unfavourable throttle and speed combinations.

Sub-Note A

"Squish" in the 1952 Norton 350 cc

Geoff Duke's autobiography (683) describes how Leo Kuzmicki, a pre-WW2 lecturer on I.C. engines at Warsaw University was working post-WW2 as a labourer at Nortons. A mechanic told their racing engineer,Joe Craig, of this and Craig asked Kuzmicki to improve the works 350 cc after the 1950 season in which Velocette had beaten the Norton in that Championship class.

Kuzmicki altered the piston and combustion chamber of the 1-cylinder aircooled engine to provide squish. A drawing of the modified parts is given below.



This drawing of the 1954 version (1084) describes the parts as follows:-
"*...the piston has a completely flat crown..(it) must..be viewed in conjunction with the combustion space in the head..in the form of a shallow dome, the base diameter of which is less than the bore; hence there is a square step between the two. Because the piston crown comes up very close to the step there is a decided squish effect as top dead centre is approached*". [Note that this description was only made public in 1955, after Norton had given up full-time works racing.]

The gain from squish was mixed with a gain from compression ratio made possible by altering the head from a bronze "skull" with Al-alloy fins cast-on to an all-Al-alloy head, both engines on 80 ON petrol. If this was worth one unit of R, say from 7.5 to 8.5, the ASE benefit would have been 4%.The actual power increase was from 28 BHP @ 7,200 RPM to 36 @ 8,000, + 28.6% (683). [There was a small reduction in Stroke to keep the increase in MPSP down to 3.7% :-

1 a/c 73.336 x 82.5 mm altered to 75.9 x 77 mm.]

Squish therefore added around 25% of power.

The overall racing result was a 4.7% increase in Isle of Man lap speed (which is close to the [Power/ All-up Weight]$^{1/5}$ correlation established by the author for that circuit between 250 cc, 350 cc and 500 cc motorcycles in 1951, which would have shown + 5.2% for +28.6% power).