Note 10
POWER and FUEL

The basic 4-stroke internal-combustion piston-engine formula for power is:-

Equation 1
$$P = \frac{BMEP \times V \times N}{894{,}890}$$

where P =Brake HorsePower (PP = Peak BHP)
BMEP = Brake Mean Effective Pressure; Bar (BMPP = BMEP at Peak Power); (BMTP = BMEP at Peak Torque)
V = Swept Volume; cc
N = Crank Revolutions per Minute (RPM) (NP = RPM at Peak Power).

The basic expression for BMEP (following Ricardo, Ref. 242) is:-

Equation 2
$$BMEP = \left[\frac{10 \times DM \times (LCV + LH) \times RSV}{1 + SAFR}\right] \times MDR \times ASE \times EV \times EC \times EM; \text{ Bar}$$

where DM = Density of (air + fuel) mixture; kg/m^3 .
LCV = Lower Calorific Value of fuel; MJ/kg
LH = Latent Heat of fuel at constant volume; MJ/kg
RSV = Ratio of Specific Volume increase, after/before combustion
SAFR = Stoichiometric Air/Fuel mass Ratio
MDR = Manifold Density Ratio when Pressure-Charged (PC) as a ratio of the value of DM when Normally-Aspirated (NA)
ASE = Air Standard Efficiency = $\left[1 - \frac{1}{R^{0.4}}\right]$
where R = Compression Ratio
EV = Volumetric Efficiency
EC = Combustion Efficiency
EM = Mechanical Efficiency,including both Friction and Pumping losses. These latter would include any net effect when Pressure-Charged, which reduces EM when Mechanically-Supercharged (MSC), and increases it when Turbocharged (TC).

Equation 2 is given as an *aide memoire* to the way that engines have been developed, but no details of efficiencies have been published for successful GP units (to the author's knowledge) - and, in most cases until recently, have probably never been measured! Ricardo's 1922 3L Vauxhall engine is the only known published example of a racing design analysed in such a way (Ref.242).

It was , of course, due to Ricardo's initiative that Tizard and Pye established in 1919 that the value of the bracketted term [ ], which is the "Ideal" MEP calculated before any efficiencies are applied, is constant to within 2% for all useable volatile liquid fuels (Refs.242,343,728). It is about **38 Bar at Standard Temperature and Pressure** (STP, i.e. 15C and 1.01325 Bar (14.696psi)). The significant differences found between fuels were:-
(1.) their resistance to knock in combustion and therefore in the Compression Ratio which could be used;
(2.) the greater evaporative cooling of alcohols which thereby improved Volumetric Efficiency.

As the alcohols (ethyl and methyl) were found by Ricardo to be highly knock-resistant as well as charge- and engine-coolers, he and Halford pioneered their use as a base for racing fuels in 1921 in a modified Triumph 500cc motor-cycle at Brooklands. Shortly after mechanical supercharging by Roots blower (RSC) was established for GP engines in 1923, alcohol-base fuels became the norm and they continued generally as such through the subsequent reversion to NA in 1952 until 1957. The parallel development of fuels in the commercial motor and aviation fields to higher knock-resistance (see Note 58) then led the companies which supplied racing fuels free-of charge for advertising purposes to press for the regulation use of 5 Star 102 Octane pump petrol "the same as you can buy at your local garage" in 1958 and thereafter. Actually AvGas 100/130 Grade was accepted 1958-1960, but 102 Research Octane Number (RON) petrol subsequently until 1983. Turbocharging (TC) had been introduced in 1977 and its special needs led the fuel suppliers to conclude that winning in itself was the major advertisement bonus and a competitive reversion occurred to special blends. These met the 102 RON test in a NA calibration engine but were much more knock-resistant than "Real Petrol" at high values of MDR in the racing units (Note 90). Post-1988, when PC was banned, the same circumvention of the spirit of the rules continued, e.g. fuel used in a 1992 Honda NA 3.5L engine produced 5% more power quite legally than "Real Petrol" to the same 102 RON (69). It seems that this was also obtained by permitting higher compression pressure but possibly such fuels beat the "Tizard-Pye Law" by small amounts (535). Fuels were even optimised differently for Qualification over a few laps and for the race. However, as shown on TABLE 1, of "The Sporting Limits"", the rules were then tightened to exclude "Power-Boosting-Additives" meaning, in effect, "Anything not in pump petrol". APPENDIX 2 gives examples of fuels used in racing over the 1906-2000 period (these data, for general interest, cover a broader range than "GP Car-of the Year").

Returning to the formula for power, combining Equations 1. and 2. and inserting the "Tizard-Pye Law" gives, near enough:-

Equation 3

$$P = \frac{MDR \times V \times N \times ASE \times EV \times EC \times EM}{23{,}550} \quad \text{HP at STP}$$

on Hydrocarbon fuel.

It is usual to achieve this NA power with hydrocarbon fuel by running 20% richer than SAFR (SAFR/1.2 = 12.3 (242)), which increases flame speed (594) and overcomes the effect of chemical dissociation ("un-burning"). The Ricardo 1922 Vauxhall 3L TT engine power curve was run at that carburetter setting, after which, to obtain the lowest Specific Fuel Consumption (SFC), it was then re-tested with a 10% weak setting (SAFR/0.9 = 16.3).*

Tests show that the gain on using Methyl Alcohol fuel in a modern NA engine at SAFR, from the greater evaporative cooling, other things being equal, is 12% compared to petrol (Ref.55. Ricardo found it to be 8% in a 1921 engine, Ref. 242). It is also possible with alcohol to use a very rich mixture (down to SAFR/1.4) to gain up to a further 10% over petrol when NA (Ref.586). This is apart from gain in ASE by raising R. Details vary according to engine design.

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Unfortunately, Ricardo did not publish the SFC data for the 20% rich "Power" test, which restricts analysis. It has not been possible to obtain the missing data from the company on recent requests. There was a Peak Power drop of 6% from the 20% Rich Mixture test to the 10% Weak setting (242).