Appendix 2
Racing and High-Power Engine fuels

(The data sources for general and racing fuel constituents are primarily:
52, 242, 294, 365, 535, 586, 592, 594, 895)

Note 10 summarises the discovery in 1919 by Tizard and Pye that the Ideal Mean Effective Pressure which can be generated by any useable volatile liquid fuel is 38 Bar at STP ambient conditions, this being the figure before the 4 engine efficiencies are applied (Volumetric, Cycle, Combustion and Mechanical). It is recorded in that Note that the differences between fuels lies in their **resistance to knock** (which restricts the compression ratio (R) and inlet charge pressure (IVP) which can be used), their **latent heat of evaporation (**which affects the Volumetric Efficiency) and the **degree of richening** which can be applied to the air/fuel mixture ratio (AFR) beyond the Stoichiometric (chemically-correct) figure for complete combustion (which enhances further the Volumetric Efficiency while decreasing the Combustion Efficiency so that there is an optimum AFR for power).

The fuel eras in this Grand Prix review period were:-

- **1906 – 1957** inclusive, with no rules concerning constituents (except 1914 when alcohol was banned);
- **1958 – 1960**, limited by rule to General Aviation petrol (gasoline) AvGas 100/130;
- **1961 – 1998**, limited by rule to 102 Research Octane Number (RON) petrol and meant to be in 1961 the highest grade (“5 star”) then available from roadside pumps;
- In practice this was evaded by the fuel suppliers during **Mid 1983 – mid 1992** when they produced fuels meeting the standard 102 RON test in a laboratory low-speed engine but which were capable of far greater performance in the racing engines of the era;
  This led to:-
- **Mid 1992 onwards** stricter rules to control Grand Prix fuel to “real petrol” of 102 RON without non-pump “power-boosting” additives, with no Tetra-Ethyl-Lead (TEL), as was becoming mandatory by then for pump fuel.

The relation of these eras to other engine regulations is shown on Table 1 of The Sporting Limits.

Appendix 2 Table collects data on various fuel mixtures consumed by racing engines 1906 – 2000, not limited to Grand Prix units but adding for general interest some other high-power engine fuels.

When GP fuel was “free” and in other racing and record engines the main constituents, with their 3 important characteristics as given above, were as follows.

<u>Constituent</u>	**Highest Useful Compression Ratio In standard test engine <u>HUCR</u>**	**Theoretical charge cooling temperature drop @ Stoichiometric <u>Air/Fuel Ratio (SAFR)</u>**	**Enrichment capability above SAFR for max. <u>power gain</u>**

<u>Petrol</u> (as used in racing fuel, excluding seasonal pump fuel additives)

Although the <u>average</u> composition of petrol is approximated by Octane (C_8H_{18}) (594) it is a mixture of many different C & H compounds and it varied constantly through the years, depending on petroleum source, refining process and additives (as opposed to <u>blends</u> with other major constituents listed below), egs.:-

1906 – 1914	5 (Retrospective)	19^{0}C	To 20% (242)
1923	7	"	"
1930 – 1939 with TEL ($PbEt_4$) additive (see Note 58-2): 87 Octane Aviation (3.6cc/ImpGal = 0.08% TEL)	8 (592,895)	"	"
1945 – 1960 AvGas 100/130 (5cc/ImpGal = 0.11% TEL)	13 (592,895)	"	"
1961 – Mid 1992 102 RON	12	"	"
Mid 1992 onward without TEL, 102 RON			

<u>Benzole</u>

HUCR depending on the distillation process from coal tar, producing varying proportions of Benzene (C_6H_6) and Toluene (C_7H_8), egs.:-

Motor Benzole with 15% Toluene	12 (895)	26^{0}C	To 22% (52,242)
"90s" Benzole with 40% Toluene	15 (52)	"	"

<u>Ethyl Alcohol</u> ("Ethanol")(C_2H_5OH)	17 (52)	86^{0}C	To 39% (52,242)
<u>Methyl Alcohol</u> ("Methanol")(CH_3OH)	17 (52)	135^{0}C	To 44% (52,242)

The higher fuel flows of mixtures including the alcohols, because of their lower calorific values compared with petrol or benzole, meant that racing teams did not use more than they had to in order to avoid extra tankage and weight and/or more pitstops, but, as competition demanded more power and therefore higher Pressure-Charging over 1924 – 1951, so a higher %age of alcohol was needed in order to cool the inlet charge down as near as possible to ambient temperature and restore air density. The rising alcohol content was needed also to cool the engine internals (see Note 17).

An important minor constituent of many fuels was **Acetone** (CH_3-$COCH_3$) (HUCR = 18 (52)) when Methanol was incorporated – but 6 different reasons have been given for its inclusion – see Sub-Note A! Obviously a very useful and versatile component in the days of "free" fuel.

It will be seen from the tabulated details below that TEL was added in several fuel formulae even when no petrol was included – expert opinion was doubtful that this was doing any good in such cases (294).

Near the end of the GP "free" fuel era **Nitro-Methane** (CH_3NO_2) was used because this comprises 52% of Oxygen by mass and so (with appropriate fuel increase) can boost power without increasing air inflow by higher RPM or pressure-charging. The return on increased power for the consumption increase of fuel necessary to burn that oxygen did not encourage large %ages in the fuels for road-racing (see the data table) as opposed to its use in eg. Indianapolis 4-lap Qualification runs (the 1965 Lotus-Ford set-up for that case used 20% NM, 80% Methanol (890), sprints and US drag-racing (up to 90% NM, 10% Methanol was used in the latter in setting 1958 records(891)).

Toluene ("Toluol") became important during the Turbo-charged (TC) era, 1983 – 1988, because it was found that, at high IVP and high N in modern combustion chambers, it could act as though it was of much higher anti-knock value than indicated by the normally-aspirated, low N laboratory control engine. Thus the 102 RON rule could be obeyed in the regulation test but exceeded in the racing cylinder. Note 90 Sub-Note A describes this situation in detail.

Engine design and operating conditions – effect on fuel requirement

Appendix 2 Table includes design and operating details of the engines using each fuel, especially an **Estimated Compression Pressure** (ECP = $IVP x R^{1.3}$), Bore B and Peak Power RPM, NP, since these are major factors in determining the fuel anti-knock requirement. An analysis of the higher-octane petrols and high-alcohol mixtures suggests that the limiting condition is something like

ECP tolerable for a given fuel proportional to 1/B.

The effect of NP has been referred –to over the years, egs.:

- In 1938 C and E Taylor (594) concluded:-
  "*...in the detonation" (knock) "process there must be a time effect*" -
  instancing Normal Heptane (Octane Number = 0) running without knock in an engine at R = 3.75 [ECP = 5.6 ATA] where compression temperature plus exhaust residual heating was well above the self-ignition level determined by the usual static test. They ascribed this phenomenon to the flame front ,accelerated by turbulence at speed, burning through the mixture before the detonation chemical process could occur.
- In 1965 Nakamura of Honda (75) showed that a 44mm Bore x 41mm Stroke = 62.3cc cylinder with R = 10.2 [ECP = 20.5 ATA] requiring 68 Octane petrol at 11,000 RPM showed a rapid decline in anti-knock need to 57 Octane at 13,000 RPM and 52 Octane at 17,000. This was not a drop in Volumetric efficiency – Honda were skilful in tuning inlet and exhaust systems to give favourable charge flow at high RPM – but the result of accelerated flame speed, according to their direct measurements.
- It was reported to the author in 2001 (892) that an Octel fuel specialist had said that current GP engines [ECP = 25 to 30 ATA] did not require high-Octane fuel because the RPM (around 18,000) did not give enough time to form the chemicals which cause knocking. Since that report NP has reached 19,250 RPM for the Cosworth CA/6 of 2006 in a 98 x 39.7 = approx. 240cc cylinder.

Appendix 2
Sub-Note A
Reasons for the inclusion of Acetone with Methanol fuel

Authority	Reason
R.Banks (614), who used it 1st in 1931 in the Rolls-Royce 'R' World's Speed Record engine:-	
"...to introduce some constituent which has a much-improved volatility... "	
(to aid starting and acceleration)	1.
L.Callingham (294), concerning its use in the R-R 'R' engine:-	
"...adding acetone...to improve its volatility... "	1.
"...higher anti-knock value than petrol or benzole ..."	2.
C.Earl (30), in relation to its use by Mercedes-Benz and Auto-Union pre-WW2:-	
"...acetone...included...as a coolant for valves and piston heads".	3.
W.Rowntree (52):-	
"Acetone...very high anti-knock value "	2.
"...and...great influence in reducing the pre-igniting tendency of methanol."	4.
H.Conway (28), on fuel post-WW2 for vintage Bugattis:-	
"...and 5% acetone for starting..."	1.
A.Bell (714):-	
"Acetone...to accelerate combustion flame speed "	5.
"and also to reduce its tendency to pre-ignite when lean mixtures are used."	4.
"..blend in 2 to 3% acetone to improve methanol's ability to mix with other fuels"	6.

Thus 6 authorities giving a mix of 6 reasons for the use of Acetone with Methanol!