Note 90
Knock-resistance in Pressure-Charged engines
(and some description of Naturally Aspirated special fuels 1989 – 1992 in Sub-Note B)

Note 58-2 describes how pre-WW2 tests with super-rich mixture in supercharged aero engines first enabled more power to be produced than the standard Naturally Aspirated (NA) variable compression fuel-rating engine would predict, by raising knock-resistance. Possibly a memory of this surfaced 40 years later, after the introduction by Renault to Grand Prix racing of the TurboCharged (TC) engine in 1977. This was 1.5 L under the Pressure Charged formula which was alternative to the NA 3 L (but never used by any firm previously), burning 102RON petrol in accordance with the current regulations and therefore needing an intercooler before inlet valve entry to reduce the temperature from the compressor.

Very-rich petrol mixture for TC

Initially very-rich petrol fuel/air mixture was employed by Renault, as in the WW2 aero engines. By 1981 their pioneering 90^0V6 (with an Inlet Valve Pressure (IVP) of about 2.7 Bar and a Compression Ratio (R) of 7 (571,909)) was consuming 250 litres in a 300 km race with a maximum of 550HP (574). The rival 3 L Cosworth DFV units had 10% less power but needed only 170 litres (544), i.e. the TC engine was running 34% richer than the NA ([250/550]/[170/500] = 1.34). The latter engine was almost certainly running for maximum power at 20% richer than Stoichiometric Fuel/Air Ratio (SAFR), i.e. at AFR = 12.2 so that the TC would have been around AFR = 9.2.

Ferrari soon followed Renault's lead on TC (CoY Egs.63, 65) and then Brabham fitted a TC BMW engine.

For all these engines the racing need was to reduce fuel consumption and a fuel was required which would pass the conventional regulation fuel test but produce higher-than-expected power at high Manifold Density Ratio (MDR).

Toluene

The well-known high knock-resistance of Toluene was investigated again. Harry Ricardo had tested this as far back as 1919 and had then proposed it, blended with varying %ages of normal-Heptane of zero knock-resistance, to form a scale to rate commercial fuels in his pioneering E35 variable-compression engine (242) (this basic idea was reused in 1927 by Edgar with the substitution of iso-Octane for Toluene and this was then adopted generally (592)).

A special fuel with equal parts of Toluene, petrol and ethyl alcohol (plus TEL) was supplied by BP for the Rolls-Royce 'R'-type engines built specially for the Miss England II and III Water Speed Record-contending motor-boats of 1930, 1931 and 1932 (52).

In WW2 Toluene was rated at rich mixture as "Over 160" on the Performance Number scale but it was not used in service fuels as it was of more value in the explosive Trinitrotoluene (TNT) (599).

Use of Toluene in motor-racing

Apparently the next use of Toluene was in an ostensibly "petrol" regulation-meeting fuel used by Porsche in their type 936 sports cars with TC F6 2.1 L engines from 1976 (608).

At any rate, for Grand Prix use initially by BMW from mid-1983 in their IL4 1.5 L TC unit Toluene was used by the German firm of BASF-Winterschall with the original Ricardo principle of blending just sufficient n-Heptane to drag it down in the conventional test to the regulation 102RON. With the higher Inlet Valve Pressure (IVP) then possible this brought Brabham with BMW engines the 1st TurboCharged Drivers' Championship (CoY Eg. 64), defeating the TC-pioneering Renault team still using "real" petrol (although with water-spray cooled intercoolers (569)).

Honda fuel details

The other teams with TC engines – which soon included Porsche (aka TAG (CoY Egs. 66, 67, 68)) and Honda (Egs. 69, 70, 71) – had to follow BMW's lead with Toluene-base fuel* for the next 5 years, 1984 – 1988, until Pressure Charging was banned once again after a programmed taper-down of TC power by limits on IVP and a new race-fuel-ration rule: 4 Bar & 195 L in 1987 and 2.5 Bar & 150 L in 1988. In 1986, before these limits came into force, Honda's 1.5 L RA166E (Eg. 68) reached IVP = 5 Bar on R about 7 and produced 1,200HP for qualification, i.e. on its Toluene-base fuel with IVP about doubled from the petrol-burning 1981 Renault it had about double the power.

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* It is amusing that the slang term for these highly-knock-resistant products was "Rocket fuel" since the bulk of liquid-fuelled rocket launches up to that time had been burning *kerosene*, a very poor resister to knock (maybe 20 Octane rating)!

As a well-reported engine (20, 535), the 1988 80^0V6 1.5 L TC Honda (Eg. 71) at the reduced-by-regulation IVP of 2.5 Bar, but with R raised to 9.4 to take advantage of the fuel to reduce fuel consumption as needed with the 150 L ration, used an 84% Toluene+16% n-Heptane fuel run 15% rich (AFR = 11.9) for Qualification and at 676HP produced 10% more power than “real” petrol (presumably run super-rich). How this fuel remained under the 102RON rule limit in the low-speed calibration engine is illustrated in Sub-Note A.

Power v. Consumption

TurboCharging led easily to the use of much higher power for Qualification at very short engine life and excessive fuel consumption in order to gain the high starting grid position which had become even more important post-1967 because the introduction of aero downforce, with its upward flowing wake, made passing more difficult. An engine change to a new unit with different settings would then be made for the race.

As a fairly extreme example, the 1988 Honda RA168E (mentioned above) on the same fuel in race tune, while retaining the regulation IVP 2.5 Bar, had the intercooling restricted to provide 70C engine inlet temperature instead of 40C, AFR increased to 13.4 instead of 11.9 and fuel pre-heated to 80C. These changes dropped power by about 10% but reduced power-specific fuel consumption by about 12% and enabled race consumption to be kept within the 1988 regulation 150 litres at winning speed.

In-race adjustments

In the TC era, apart from their throttles which tended to be either wide open during acceleration (64%) or shut while braking (20%), with 16% of juggling in corners (20), all drivers were provided eventually for the race with several power settings by push-button adjustment of the electronic Engine Management System, from “Max. Power” for overtaking to “Min. Consumption” as described above, relying on their attention to a sophisticated fuel gauge to ensure that they finished. There were further electronic aids by data telemetered to the pit staff and 2-way radio to permit pit managers to control their employees (theoretically!). Direct engine resetting by radio from the pit would have been possible but was banned.

Continued on page 3 Sub-Note A

Sub-Note A

Toluene-base fuel in Calibration and in Racing engines

There is an interesting comparison between the 84% Toluene+16% normal-Heptane fuel used by Honda in 1988 in the RA168E 80^0V6 TurboCharged 1.5 L (running at optimum 15% rich) and the blends of those constituents tested by Ricardo in 1920 in his E35 Naturally.Aspirated variable-compression 2.1 L research engine (1 cylinder Bore (B) 4½''/Stroke (S) 8'' = 0.563), as described in (242).

Although those early tests were limited to 79% Toluene+21% n-Heptane and reached Compression Ratio (R) of 7.5 a reasonable extrapolation of the data shows that an 84/16 mix would have reached R = 9. This compares with the RA168E operating at R = 9.4 ***on top of an Inlet Valve Pressure (IVP) of 2.47 Atmospheres Absolute (ATA)*** (2.5 Bar rule). The reason for the far superior knock resistance of the Japanese engine must lie in the following differences:-

	E35	RA168E
B/S	4½''/8'' = 0.563 (114.3mm/203.2)	79mm/50.8 = 1.555
1 cylinder volume cc	2,085	249.0
Manifold Density Ratio (MDR)	1	2.27 (2.5 Bar at 40C)
RPM	1,500	12,500
Mean Piston Speed (MPS) m/s	10.16	21.17
Inlet charge Mean Gas Velocity (MGV) m/s	25.71	68.73
(Squish Lands / Piston Area)	-23.5% [i.e**. Negative** because the Combustion Chamber was 5'' dia. over 4.5'' bore]	15%
Flame Travel mm	57.15 2 x Side plugs	39.5 1 x Central plug
Combustion Chamber (Surface Area / Volume) cm^{-1}	1.3 @ R = 9	≈ 3.*3* @ R = 9.4 (assuming squish lands were not part of the chamber)

Most of the factors listed were favourable to the RA168E in resistance to knock although it is impossible to apportion shares.

The above comparison illustrates the way in which a fuel rated in the standard calibration engine, which was similar in principle to Ricardo's E35 (the CFR 1 cylinder 3¼''/4½'' = 0.722) could nevertheless give far superior performance in a modern Pressure Charged racing engine

Continued on page 4 Sub-Note B

Sub-Note B

Special fuels in Naturally Aspirated racing engines, 1989 –mid 1992

Following on from their success in outflanking the 102RON petrol limit in TC engines the fuel suppliers in the ensuing 3.5 L NA era produced special blends for the same purpose. It seems that these also produced extra power by permitting higher compression pressure than could be used without knocking on “real petrol”, to judge by the change found necessary by Renault (burning Elf fuel) in mid-1992 when the fuel rule was tightened to exclude *“Power-Boosting-Additives*”. According to (919) this required revised ignition settings in the RS4 engine which, in the context of reduced power, could only mean a *smaller* ignition advance before TDC. This *may* have been a temporary expedient until lower compression pistons could be obtained.

In the Honda RA122E/B engine at the same date the fuel change resulted in a power drop of 5% (816PS to 775PS)(69). On the basis of Air Standard Efficiency this drop would occur if Compression Ratio (R) was dropped from the stated 12.9 to 10.5. There may have been some offsetting gain of Mechanical Efficiency which would have reduced the drop of R required and there may have been some alternative retardation of the ignition, as in the Renault. Expressing the power drop only as reduced R looks unlikely and it is possible that the special fuel (Shell in the Honda case (535)) *had* beaten the “Tizard-Pye law” (see Note 10) by a small amount.

Fuel 2000 – 2009

In the series of BMW Grand Prix engines over 2000 -2009, ref (1095) states that, despite the tighter fuel regulations, it was still possible over that period by fuel development to obtain a 1% performance increase and a 2% reduction in consumption.