A Century of Grand Prix engine weights, 1906 – 2005

A general picture of engine weights for the "Grand Prix Car-of the-Year" (CoY) from 1905 onwards has been shown in Fig. 02 of the "Overview of Performance" section of this website. The figures are recorded in Appendix 1.

While it is easy to weigh engines, a meaningful study of this parameter is difficult, because:-
(A): the definition of what is included is variable;
(B): it is time-dependent as materials evolve and there appear unforeseeable flashes of design genius.

Regarding (A), the difference between engine weight as usually published and the figure which the car designer needs – the *installed* weight– has already been discussed in Note 123.

The obvious omissions are the water-cooling and lubrication systems (all units considered here were water-cooled; in later engines a lot of the waste heat was removed by the oil). It is probable that the weights of these systems were a function of power output.

The exhaust system – essential for performance post-1951 – is also never published, nor is the air inlet system which became important post 1970.

Despite these reservations, some progress has been made to find an underlying factor to correlate the data. In the first instance this has been done for Naturally-Aspirated (NA) engines in the 1NA, 2NA and 3NA Eras.

Regarding (B), the data have been plotted on a date basis so that the material and design changes can be identified readily.

Variation of Weight (W) with Swept Volume (V)

In the 1NA era, 1905 – 1923, there was a variation of V from 16.3 Litres to 2 Litres (x 8.1). Since all engines of this era were of iron or steel static structure, this has been used to consider a relation of:_

$$\mathbf{W \propto (V)^{1/3}}$$

Variation of Weight with Cylinder Number (CN)

Although partly outside the selection of CoY, the series of racing engines built by Coventry Climax over 1953 – 1965, from the FPE to the FWMW, have the great merit for correlation purposes of being:-

- All Al-alloy static structure9 engines;
- All DOHC;
- All designed, detailed, manufactured and tested under the technical direction of one man, Walter Hassan.

The 9 engines for which weights are available (see P.6) cover a V range of 1.5 Litres to 2.5 Litres but, more importantly, a CN range of 4, 8 and 16. This data has been used to consider:-

$$\mathbf{W/(V)^{1/3.} \propto (CN)^{1/6}}$$

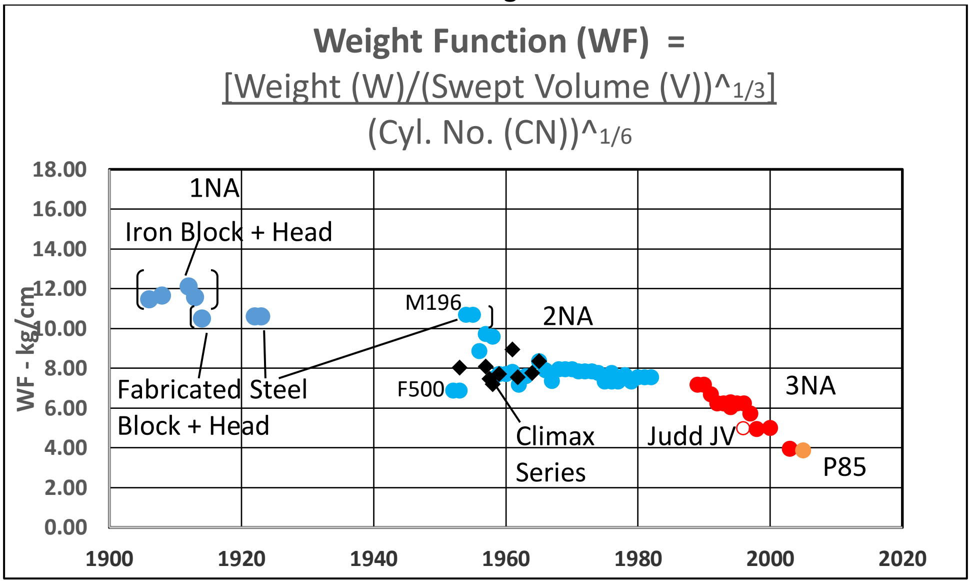
Weight as a function of Swept Volume and cylinder Number

With the definition of:-

$$\mathbf{Weight\ Function\ (WF) = (W)\ /[(V)^{1/3} \times (CN)^{1/6}]} \quad \text{kg/cm}$$

Fig. 1 has been plotted as **WF** versus **Date** on P.2.

Fig. 1



Comments on Fig. 1

- The difference is shown between the 2 forms of Fe-alloy static structure:-
  Cast-iron block with integral head;
  Fabricated (welded) steel block with integral head, which saved weight.
  The latter was introduced by Daimler in their DF80 aero-engine entry for the 1912 Kaiserpreis (see ILLUSTRATIONS for Appendix 5 at Fig. 2). It was used for their 1914 GP engine, M93654. They persevered with it for their racing engines up to the 1954 – 1955 M196. [It is very interesting that for the 300SLR engine derived from the M196, Mercedes-Benz were prepared to accept a completely novel construction:- the block and integral head were in cast Al-alloy *and no cylinder liners were fitted!* The bores instead were Cr-plated. This was completely successful and 40 years ahead of others. No direct comparison of weights is possible because the figure for the Al-alloy engine included a starter and dynamo suitable for the 24 Hours of Le Mans.]
- Al-alloy pistons were introduced to GP engines after WW2 to reduce reciprocating mass, which also reduced total weight.
- All Al-alloy static structure (except for cylinder liners) began in 1932 with the PC Alfa Romeo type B ("P3") and in the 2NA Era all engines except the M196 used this construction.
- The low WF value for the 1952 – 1953 Ferrari type 500 can be attributed to these units having screwed-in wet cylinder liners. This construction was revived by John Judd in 1996 in his very-light type JV (see later comments under 3NA).
- No reason is known for the high WF of the 1957 Maserati, but the similar figure for the 1959 Ferrari type 246 is probably due to a 6-pin crank in the 65°V6 to give even firing. When Carlo Chiti designed the 1961 type 156 he chose a 120° bank angle for the V6 to permit a 3-pin crank and save weight.
- The long series 1968 – 1982 is, of course the Cosworth DFV. Slight weight reductions were made in this time, particularly Al-alloy cylinder liners in 1979. An attempt in 1977 to save 12% of weight with a Mg-alloy cylinder block was unsuccessful. The V8 DFV run was interrupted for CoY 3 times by the F12 Ferrari type 312B whose WF value was similar.

Comments on 3NA weights

Clearly, something was going on in the 3 NA Era, 1989 onwards (extended to 2005 with Significant Other examples from Appendix 1)., which resulted in the steady decrease of weights!

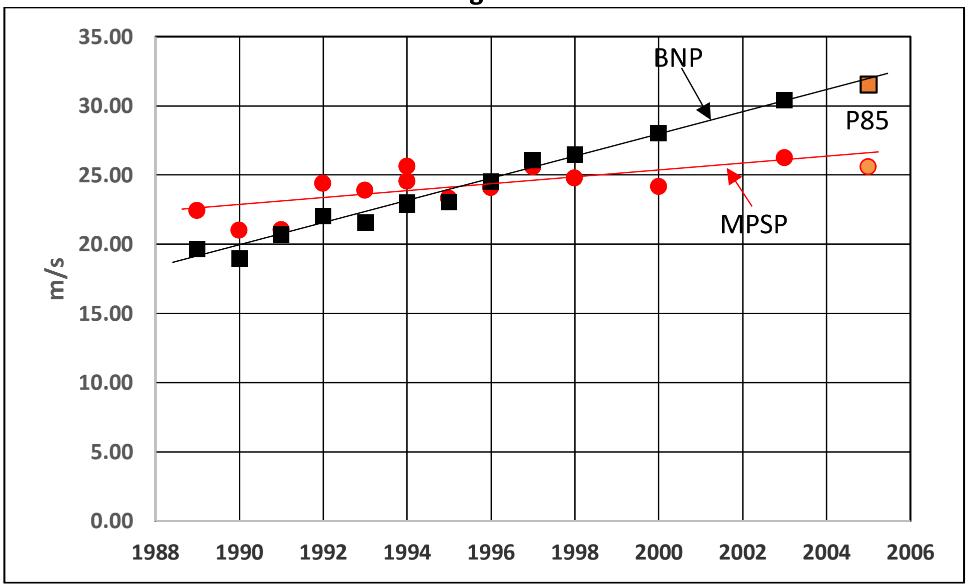
An immediate thought is that the decrease in weight was associated with the large increase of Bore/Stroke (B/S) ratio during the Era.

In order to raise Volume Specific Power the engines needed to run to higher RPM. As the available piston material meant a near constant Mean Piston Speed (MPSP) (see Note 13 Part 1) this required a shorter stroke, i. e., an increase in B/S ratio. This in turn required a higher Mean Valve Speed (MVSP). This latter was made possible in the 3rd Era by 3 advances in valve gear:-

1. All Ti-alloy valves, replacing steel/NiCr-alloy, to reduce reciprocating mass – also giving a reduction in engine weight;
2. Pneumatic Valve Return System (PVRS), replacing steel coil springs to eliminate the surge limit – this also giving a valuable reduction in engine weight at the top end.
3. Diamond-Like Carbon (DLC) surface coating to reduce friction in the valve gear.

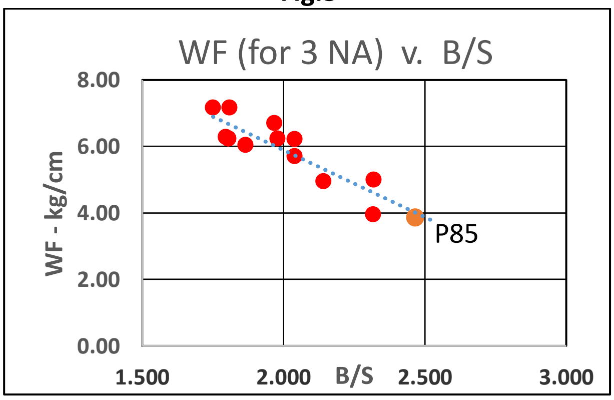
There is insufficient data to give the increase in MVSP made possible by these advances, but Note 13 Part 3 explains that a surrogate for this parameter for a given type of gear is Bore Speed (BNP). Fig. 2 shows MPSP and BNP for the 3rd NA Era.

Fig. 2



It does seem from Fig. 3 below that , in the 3rd NA Era at least, there was a significant effect on engine weight from B/S ratio.

Fig.3



This implies that the saving in weight by reducing the engine height was more than the increase from the greater length. Certainly, efforts were made to keep the length down by reducing the land between cylinders. DASO 1095 reported that in the (non-CoY) BMW engine series the land was cut from 13 mm in 2000, to 8.5 in 2001 and finally to 4 mm in 2005 with an integral block-cum-head. To show how this important dimension had evolved, obviously with improved sealing at the block/head joint until (once again) there was *no* joint, the 1953 V8 2.5 Litre Climax FPE land was 30.6 mm (1.2'' between 3'' bores. DASO 57).

The reduction of weight and WF in the 3NA Era was therefore a mixed consequence of increased B/S ratio with design and material changes, the latter two also including:-It was made possible by a large increase in funding as a result of sponsorship from TV coverage.

- Adoption of Ti-alloy con. rods in place of steel, primarily to reduce reciprocating mass but also lowering engine weight;
- The stimulus to all other designers in 1996 of the John Judd-designed type JV (sponsored by Yamaha as OX11) with a V10 3 Litre weight of only 105 kg (DASO 1191), reviving the screwed-in wet cylinder liner. The magnitude of this improvement can be judged from the weight of the 1996 CoY, the Renault RS8, which was 132 kg. The JV was 20% lighter. It was not very reliable but this may not have been associated with the light weight. No other maker adopted the screwed-in liner.
- In 1998 the introduction by Ilmor-Mercedes of 62Be/38Al alloy pistons for the FO110G in place of Al-alloy, with the same dual reciprocating/overall gain mentioned above. This unit, which was not liner-less (although Cosworth were trying that), got down to the same weight as the JV, 105 kg.
- The 2000 Ferrari 049 also achieved the same weight reduction without going liner-less, but apparently by reducing the inter-cylinder lands.
- As mentioned above, in 2005 the BMW P85 was built with integral block and head and liner-less to achieve W = 85 kg and **the lowest WF of the century at 3.87 kg/cm.**
  It was not raced because the FIA made a very-late change to increase the life required for F! engines and the P85 had been optimised to the previous rule. It was the last Grand Prix engine designed with a free choice of B/S ratio and without an FIA-regulated minimum weight.

The end of Grand Prix weight reduction

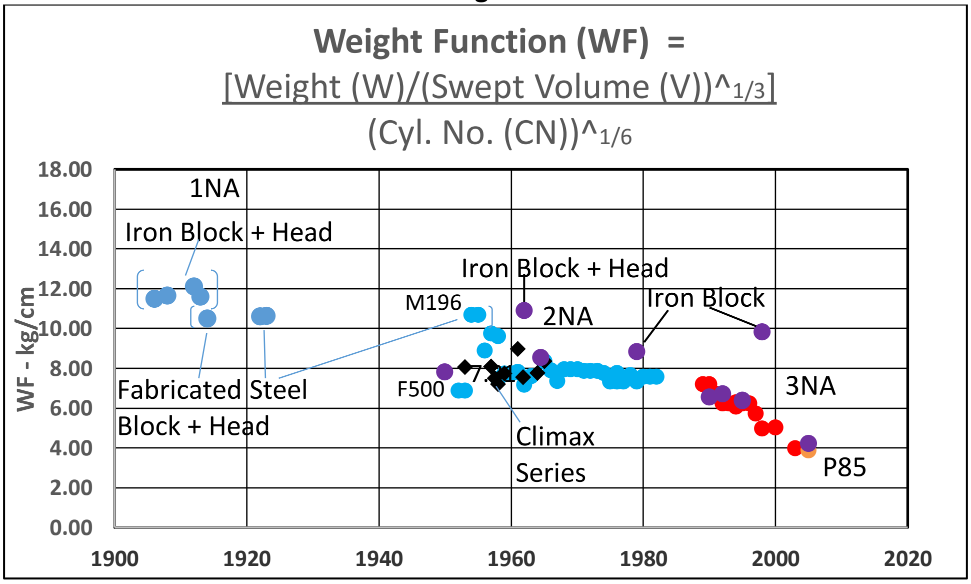
The FIA had decreed for the new engine formula beginning in 2006 that the weight must be 95kg for a 90V8 2.4 Litre, with a bore not exceeding 98 mm (many other detailed restrictions also applied). BMW stated (DASO 1095) that they could have built an engine of that configuration weighing 69 kg, i.e. WF = 3.65 kg/cm. As this was only 6% different from the P85 for a 20% smaller Swept Volume and 8 cylinders instead of 10 this seems to be good support for the Weight Function.

Similarly, for the further engine formula of 2014 the FIA again fixed a minimum weight. Whether engine designers will ever again be allowed to exercise their skill to reduce weight is, of course unknown.

"Significant Other" engines on the WF chart

For general interest, Fig 4 plots the NA engines in the extension of Appendix 1 onto the same basis as Fig. 1 (purple spots).

Fig. 4



The reasons for the points which are away from the main trends are:- (Contd. on P.5)

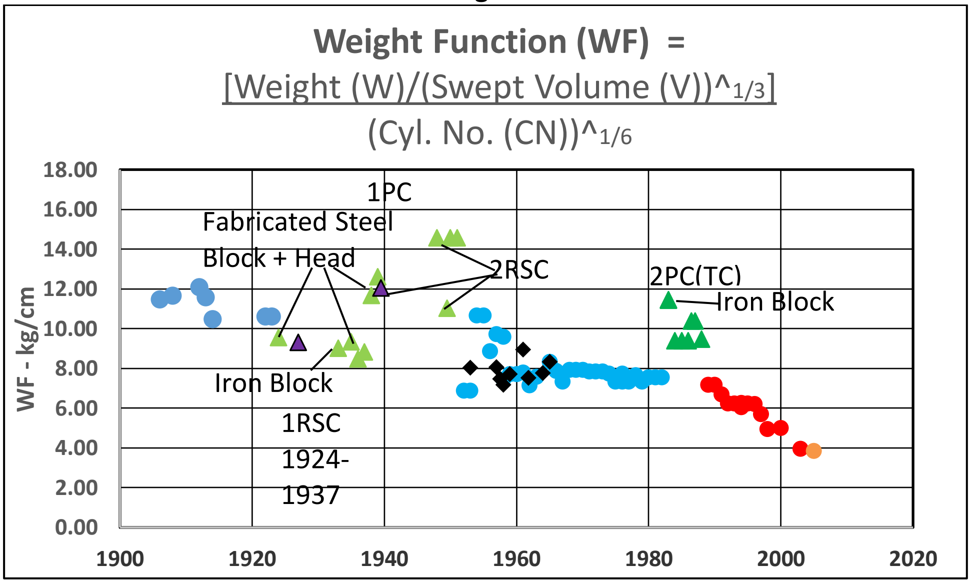
Contd. from P.4

- !962/WF = 10.89:- This was the Offenhauser Meyer-Drake IL4 4.2 Litre of that year, which had an iron block with integral head;
- 1979/ WF = 8.82; BMW M12/7 IL4 2 Litre Formula 2 engine, which had a production iron block;
- 1998/WF = 9.81; Ford 90V8 5.8 Litre engine tuned to NASCAR regulations with a production iron block.

Pressure - Charged (PC) engines on the WF chart

From Appendix 1 the CoY PC engines for the 1PC Era (1924 – 1951) (pale green triangles) and the 2PC (TurboCharged (TC)) Era (1983 – 1988) (mid green triangles) have been added to Fig. 1 on Fig. 5.

Fig. 5



Unfortunately, weights for most of the 1PC CoY engines from 1925 to 1934 are not available, i.e. for the Delages, the Bugattis and the Alfa Romeos. The Delages and Bugattis were all iron blocks with integral heads. If any visitor has any of these figures the author would like to hear from them on the Contact tab. The exception is the iron block Maserati IL8 8C3000 at 1933/9.03. It is a pity that the 1932 Alfa Romeo type B IL8 2.65 Litre cannot be plotted because it was the Grand Prix pioneer of all-Al-alloy static structure (apart from dry steel liners), block and head being integral.

All PC CoY engines in the 1PC Era were mechanically Roots-supercharged:- from 1924 to 1937 this was 1-stage (1RSC); in 1938 the Mercedes M154 had two blowers in parallel; from then to the end of the Era 2 blowers were fitted in series (2RSC) (the author would like to hear from anyone who has weight data for Roots blowers).

The low point at 1936/8.49 was the Auto Union 45V16 6 litre engine with Al-alloy static structure with wet steel liners.

. It is not known why the 1948/1950/1951 Alfa Romeo type 158/159 IL8 1.5 Litre engines plot at such a high value of WF (unless the data are wrong; the author would be glad if they could be confirmed or corrected). The 1949 Ferrari type 125GPC/49 had a much lower WF.

“Significant Other” engines in the 1PC Era

_To complete the PC data for the 1924 -1951 Era, 2 units from the “Significant Other” section of Appendix 1 are shown (purple triangles). The 1927/9.31 engine was the Miller-Lockhart IL8 1.5 Litre which was iron block with integral head and with 1 *centrifugal* supercharger. The 1939.5 point at 12.07 was the Mercedes Benz M165 90V8 1.5 Litre (tested with 2RSC but not raced). It plots very near its “big brother” M163 which was 60V12 3 Litre, which again supports the value of the Weight Function.

2PC (TurboCharged (TC)) engines, 1983 - 1988

All the TC engines had an inward radial-flow 1 stage turbine driving a 1 stage centrifugal compressor. The weight of the intercooler (though essential) was never included in published data (again, the author would be glad to be informed of the figures)

The 1983 point at WF = 11.44 was the BMW M12/13 IL4 1.5 Litre with a production iron block. While the Honda 80V6 1.5 Litre engines in 1986/87/88 had iron blocks, these were special thin-wall castings with wet cylinder liners.

Coventry Climax

Year	Type	V cc	W kg	CN	B mm	S mm	B/S	WF kg/cm
1953	FPE	2479	154	8	76.2	67.945	1.121	8.05
1957	FPF	1476	116	4	81.28	71.12	1.143	8.09
1957.5	FPF Mod	1964	118	4	86.36	83.82	1.030	7.48
1958	FPF Mod	2207	118	4	88.9	88.9	1.000	7.20
1959	FPF GP	2496	132	4	94	89.9	1.046	7.73
1960	FPF GP	2496						
1961	FPF Mk2	1495	129	4	81.79	71.12	1.150	8.96
1961.5	FPF Indy	2751						
1961.8	FWMV 1	1495	122	8	62.99	59.94	1.051	7.55
1963	FWMV 3	1496						
1964	FWMV 5	1497						
1965	FWMV 6	1497	135	8	72.39	45.47	1.592	8.35
1965.1	FWMV 7	1497						
1964	FWMW	1495	141	16	54.1	40.64	1.331	7.77
1966	FWMV 10	1974						

DASO:- FPE & FPF (33); FPF/Mk2 (56); FWMV/1 (1071); FWMV/6 (34);
FWMW (AC 19 Feb. 1965) & (34)

Performance data for Coventry Climax are given in Note20.

D.S. Taulbut.
16 November 2016.