Note 18

Bearings Development

An attached Table (P.8) details the types of bearings used for the crankshaft Main Journals (MJ) and Crankpins (CP) of successful Grand Prix (GP) engines in the 1906 – 2000 period of this review. They divide broadly into 3 groups, although each group has certain exceptions:-

1st group: 1906 – 1921 Plain Whitemetal;
2nd group: 1922 – 1939 Roller and Ball;
3rd group: 1947 – 2000 Plain "thinwall" copper-lead-indium.

A detailed discussion is given below for each group, after a general introduction.

General Introduction

Plain Bearing Theory

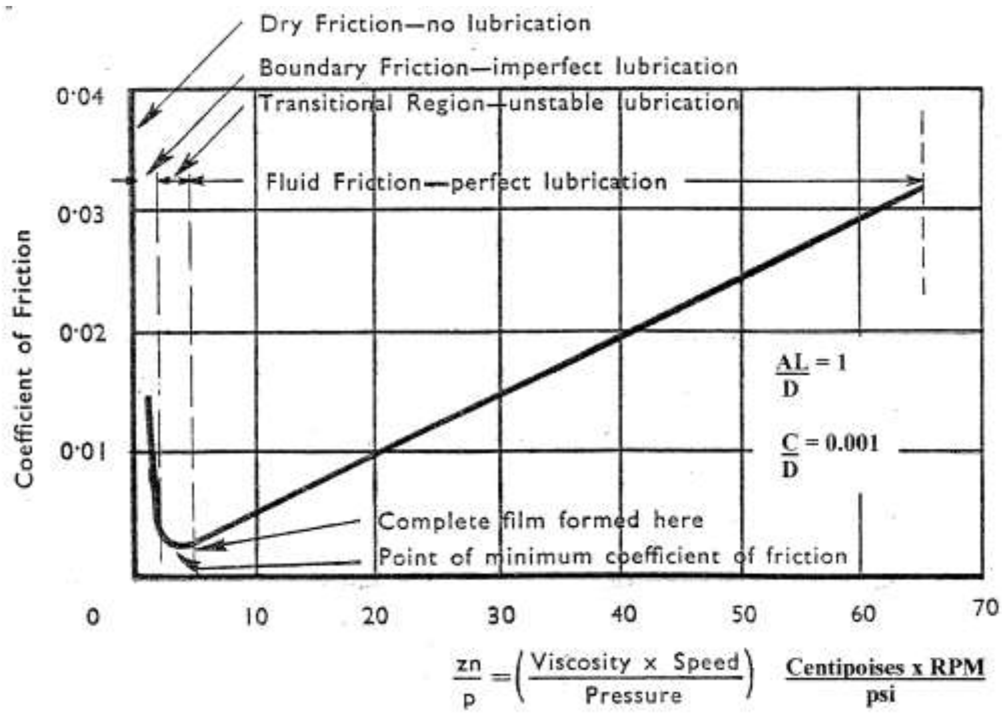
In a simple lubricated plain journal bearing the load-carrying capacity and the friction coefficient are determined by the non-dimensional parameter:-

$$\left(\frac{ZN}{P}\right)$$ (the full expression includes the Clearance/Diameter (C/D) ratio)

where:- Z = Viscosity of the oil at the temperature *inside* the bearing;
N = RPM;
p = Pressure, defined as:- Load carried per unit of projected Area, and Area = pin Diameter (D) x Axial Length (AL);

provided that $\left(\frac{ZN}{p}\right)$ is above a critical minimum,

after which the hydrodynamically-self-generated oil pressure *inside* the bearing carries the revolving pin clear of the static casing (625,626). The figure below from (625) illustrates the characteristic relation of Coefficient of Friction to $\left(\frac{ZN}{p}\right)$.



The above diagram is the "Stribeck curve" named after the German researcher who proposed it in 1902.

Since the internal oil pressure (whose components in the direction of the load integrate to 'p') has to be reacted on the bearing material the latter has to be capable of resisting it at the local oil temperature for the desired life. The characteristics of the material (and of the oil) are also of major importance during the start-up phase when $\left(\frac{ZN}{P}\right)$ is below critical. The lining's ability to absorb any grit in the oil without damage to the pin is also important.

Load and Speed variations

In a piston engine the cyclical loads on the "Bottom-End" bearings and the angular speed variation of the connecting-rod bearings add extra terms but these are favourable to load-carrying. This is seen in the simplicity of the highly-loaded Gudgeon Pin bearing, where the direction of rotation reverses during each crank revolution,: splash-lubricated hard bronze bushes supporting steel pins have remained scarcely changed (except to copper-lead material post-WW2) throughout the **h**istory of the internal combustion piston engine.

Frictional Power Loss

The frictional power loss in a plain lubricated bearing, running above the critical value of $\left(\frac{ZN}{P}\right)$ where the Coefficient of Friction is then approximately proportional to the parameter, is given by :-

$$\text{Power Loss proportional to } Z \times V^2 \times AL$$
$$\text{where } V = \text{peripheral velocity of the pin}$$
$$\propto \pi \times N \times D$$

(625,626)

Plain Bearing Axial Length/Diameter (AL/D) ratio

In order to reduce the oiled area and hence the frictional loss, the Axial Length/Diameter (AL/D) ratio of plain bearings has been reduced steadily with time as shown below:-

Date	Engine	Data Source	Average AL/D	Mean Piston Speed (MPS) m/s
1889	Daimler 14^{0}V2 0.6 L	SO 1	2.7	2.0
1895	Panhard IL2 1.2 L	SO 2	1.87	3.2
1908	Mercedes IL4 13.5 L	Eg. 3	1.59	9.6
1921	Duesenberg IL8 3 L	Eg. 7	0.94	16.6
1927	Miller IL8 1.5 L	SO 9	0.8	20.6
1932	Alfa Romeo IL8 2.65 L	Eg. 18	0.5	18.9
1936	Auto Union 45^{0}V16 6 L	Eg. 22	0.32 MJ only	14.2
1949	Ferrari 60^{0}V12 1.5 L	Eg. 27	0.46	13.1
1957	Maserati IL6 2.5 L	Eg. 35	0.47	18.8
1965	Coventry Climax 90^{0}V8 1.5 L	Eg. 42	0.55	16.3
1967	Cosworth FVA IL4 1.6 L	Note 79	0.43*	20.7
1992	Honda RA122E/B 75^{0}V12 3.5 L	SO 20	0.45	23.0
2002	BMW 90^{0}V10 3 L	(1095)	0.5	26.1

The reduction of AL/D in the Auto Union bearings, although with the 1st copper-lead lining (see later), proved to be a step too far for the crank pins, which may have been as low as 0.28, when the engine was enlarged to 6 L in 1936 (the original capacity was 4.4 L), probably because there was too much oil leakage. These bearings had to be converted to rollers (with solid races on a Hirth-type built-up crank).

After the introduction of "thinwall" linings in the post-WW2 Ferrari (see later) the average value of AL/D was generally around 0.5, as shown.

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*FVA: individual AL/D were:- MJ = 0.47; CP = 0.39. The Cosworth DFV AL/D for CP was the same 0.39.

1st Group

Whitemetal bearings

For the main journals and big ends of the 1st group of engines a very good bearing lining was available in a compound patented by Babbit in 1839, being Sn 89%/Sb 7%/Cu 4% or thereabouts

(625) and sometimes called by the patentee's name or alternatively "whitemetal". This would run against an unhardened steel shaft (170 Brinell) and was almost proof against acids produced in the oil during running of an internal combustion engine. It was capable of supporting around 12 MPa (≈ 1,700 psi) average pressure provided that surface temperature did not exceed 100C (610,626).

Whitemetal provided a sufficient racing life up to 1914, when the Mercedes IL4 4.5 L ran up to a "Red line" of 3,450RPM, equal to a Mean Piston Speed (MPS) of 19 m/s (468).

Early improvements in the 1st group

During the time period of the 1st group lubrication systems for plain bearings were developed from early "gravity + splash" arrangements (621)* into full pressure supply. The "dry", i.e. scavenged, sump with a separate oil tank appeared in the 1913 Peugeot (4).This provided cooling of the oil.

Crank design also advanced in this period from simple to counter-balanced to reduce journal loads

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*Although relating to a non-Grand Prix pure-sprint engine, (446) gives an interesting account of how in 1923 a customer specification "Brescia" IL4 1.5 L Bugatti with whitemetal bearings lubricated by a "Squirt-and-hope" system were made to stand an MPS of 20 m/s for a very short life by fitting oil pickup-scoops on the crank webs, a modification designed by Amherst Villiers.

Early bearing design

In the racing engines of the 1st group the whitemetal was used in a thick lining cast into thick bronze or steel shells (except the 1921 Duesenberg crank pin bearings which anticipated later "thinwall" bearings by having a reduced thickness of whitemetal cast directly into the tinned con-rod and its cap (711). This approach had been used previously by Henry Royce in the 1914-designed V12 20.3 L Eagle aero-engine. The Duesenberg apart, such bearings did not have the heat transfer advantages which were produced by the 1930 invention by Hopkins and Palm of the Cleveland Graphite bearing company of the "thinwall" steel shell with only 0.7mm whitemetal lining (625) – which was halved later(610). This is the type of bearing brought to the UK by G.A. "Tony" Vandervell in the '30s (68), of which more later.

The 1913 Peugeot exception to the 1st plain bearing group

There was a partial harbinger of the 2nd Roller & Ball bearing group and an exception to the 1st plain bearing group in the Ernest Henri-designed 1913 Peugeots. The IL4 5.6 L and 3 L engines for the Grand Prix de l'ACF and the Coupe de l'Auto races, respectively, had 3 ball races (one double) to carry the 2-piece bolted-up crank in a barrel case. The big-end bearings remained plain whitemetal.

Post-WW1 Henri engines and the Floating Bush

It is interesting to describe here the post-WW 1 1919 -1921 Henri engines which he designed for Ballot. The 1913 idea was extended to his new IL8 engines of 4.9 and 3 L for Indianapolis and the French GP. These had 5 ball races (2 double) on a 4-piece bolted-up crank. The plain big-end bearings were of a type which has drawn unfavourable comment (4,26), having a fully-floating bush, white-metalled on each side, between the rod and the pin. These comments overlook the high-speed performances of the engines at Indianapolis and in the 1921 inaugural Italian GP at Brescia (1st and 2nd), also the 2nd and 3rd places won in the 1922 Targa Florio by the identical design in the Ballot 2LS sports car (26).

It is also a fact that Harry Ricardo removed a big-end bearing RPM limitation on the Bristol Jupiter radial 9-cylinder 28.7 L aero engine by introducing a 1-piece floating bush, white-metalled on both side and perforated for oil passage, with a 1-piece master rod, a design retained on all Bristol engines until the early '40s (343,626,632). Henri's floating bushes were made in 2 parts fitted in bolted-up rods, which Ricardo tried but found inadequate but it seems that Ballot workmanship was good enough for its purpose.

Oil pre-WW1

Early engines used mineral oil. Castor oil was introduced by Wakefield in 1909 for aero engine use and had its first major racing engine success in 1911, when it was used in the Senior TT-winning Indian motor-cycle. The following year it lubricated the engines of the Coupe de l'Auto Sunbeams which finished 1st, 2nd and 3rd (1099). Thereafter it was used generally for many years. Castor oil, like other vegetable-base lubricants, has greater "oiliness" than mineral oil, a property identified by later research as shifting the transition point on the Stribeck curve to a lower value of (ZN/p) (594).

Consequently it protects bearings better in the start-up phase. It is also more adhesive than mineral oil.

<u>2nd Group</u>

Bugatti used all rolling bearings in his “works” IL4 1.5 L Voiturettes which triumphed at Brescia in 1921. At the same date, in the Grand Prix arena, FIAT fitted all roller bearings to their 1921 IL8 3 L , introducing split races and cages so as to retain a 1-piece crank. They continued these features in their subsequent racing car engines to 1927, (after which they concentrated on Schneider Trophy aero engines).

The Sunbeam engines of 1923 -1925 copied the FIAT bottom-end practice. Delage also followed FIAT’s lead in the 1923 60^0V12 2 L (allegedly this engine, with camshaft and auxiliary drives also on rolling bearings, had over 100 of that type (455)). Alfa Romeo, with ex-FIAT designer Vittorio Jano, kept the Turin firm’s bearing practice in his 1924 IL8 2 L P2, as did the 1926-27 IL8 1.5 L Delages, Bugatti over 1924-1931 also retained all roller & ball bearings in his IL8 2 L, 1.5 L and 2.3 L units.

<u>Plain bearing exceptions to the 2nd group</u>

While European engines were using rolling bearings, an American maker, Harry Miller with his IL8 1.5 L engines, was showing what *could* be done with plain whitemetal even when highly supercharged and running up to a Mean Piston Speed (MPS: MPSP at Peak Power) of 20 m/s, racing at high speed over 500 miles at Indianapolis (6).

The all-rolling-bearing engines, while of higher Mechanical Efficiency than plain bearings with AL/D around 1, must have been not only much heavier but also much more expensive in initial and running costs because of their numerous high-precision parts and short lives resulting from high contact stresses. Furthermore, a roller big-end, because of the variable peripheral speed, tends to have the rollers skid and incur flats if accelerated too rapidly when the oil is cold and thick (although they *do* avoid the low (ZN/p) problem of plain bearings). Therefore, in the shortage of money for motor-racing after the world depression reached Europe in 1930, the cheapness of plain whitemetal bearings led to their revival for Grand Prix racing in 1932-1934.

Jano, in particular, had built up his experience of plain bearings in the series of Alfa Romeo 6C and 8C sports cars beginning in 1925. He then used them in the pure racing Tipo B (or “P3”) Monoposto of 1932 with a value of AL/D reduced to 0.5, which would have reduced the frictional loss. He continued them in all his subsequent Grand Prix designs (except using rollers for the big ends of his enlarged 60^0 V12 4.5 L of 1937 (25)).

Maserati also used mainly plain bearings in their 1933 8CM, and they were Ferdinand Porsche’s choice for his 45^0V16 4.4 L P-wagen design which he sold to Auto Union in 1933.

<u>Copper-Lead bearing material</u>

Porsche did not seek ultimate RPM from his P-wagen engine and, as a private venture, probably kept its cost down with the idea of selling it to the new Auto Union group who were less well-endowed than Daimler-Benz, hence the plain bearings. However, he made use of a new material which had just been proven for aero engines. This was Copper-Lead (around 69% Cu, 30% Pb, 1% Sn) (usually called “Lead-Bronze” but Copper-Lead better reflects the low Sn content). It had been brought to successful practice in the mid-‘20s by Norman Gilman of the US Allison Engine Co. It consisted of a *mixture*, not a compound, of a Cu-Sn matrix filled with Pb, the latter smearing over the surface in start-up to provide the bearing surface. The basic problems, of keeping the material adhering to the still thick steel backing shell and of protecting the Pb from settling, had been solved by quenching after casting into the pre-heated shell. This initially-secret process was patented in 1926 (628). Charles Lindbergh’s TransAtlantic Wright J5 9-cylinder 13 L radial engine in 1927 was fitted specially with the new type of Allison bearing and gave it a great advertisement. Compared with whitemetal, both in “Thick-wall” form, Copper-Lead offered 25% higher pressure capability to a higher temperature (626). Being harder it required a pin of around 270 Brinell, better oil filtration because it could not embed grit very well and more accurate alignment since it could not distort to accommodate errors.

Having been bought by General Motors in 1929 Allison in 1932 developed for GM to produce an automotive steel-strip-backed Copper-Lead bearing (presumably following the Cleveland “Thin-wall” pattern of whitemetal type already mentioned). It may be that Porsche was the first European user of such bearings and, as Allison guarded their process well – e.g. Rolls-Royce had to buy a licence and pay royalties to use it (628) – he must have paid for the privilege. The rather-daring reduction of AL/D in the P-wagen engine has already been mentioned.

Reversion to rolling bearings by Mercedes-Benz

When Mercedes-Benz re-entered the Grand Prix arena in 1934 with "cost-no-objection", and also true to their "advanced-but-conservative" policy, they used the split race and cage approach to employ roller bearings on a solid crank through to the time in 1939 that their country, once again, forced a halt to racing with another war.

Auto Union mixed bearings

It has already been described how Auto Union in 1936, when enlarging the engine to 6 L, were forced by the retained original 1934 crankcase dimensions to move from the first choice of plain bearings to rollers for the big ends.

Oil in the inter-War period

Castor oil was used generally in WW1 aero engines, both in rotary units and also in "stationary" engines. However, it had the unsatisfactory property of oxidising easily, leading to tenacious deposits. Therefore, in 1923 Harry Ricardo ran tests for the Air Ministry in an aero engine with a new Shell light mineral oil. This gave 10% more power than the previously-used castor oil, with "perfect" lubrication This was followed by tests in racing cars at Brooklands which produced 3% higher lap speeds, also consistent with + 10% of power (294). Thereafter racing had a choice of lubricants. Some people preferred to stay with castor oil because of the greater protection in the transition region.

Auto Union introduced an oil cooler into the scavenge line in 1936 (4), thought to be a 1st which became usual afterwards.

3rd Group

The return to plain bearings

The period of the 3rd Group in Grand Prix racing opened with the domination of the Alfa Romeo type 158-developed-to 159, which had been designed originally as a Voiturette by Gioachino Colombo in 1938. As the principal assistant to Jano during the'30s he had followed his former chief's later practice and adopted plain bearings for this engine and it is probable that these were Copper-Lead. By 1938 this material was in full aero use and was well-known for automobile use also, particularly in Diesel engines with their high peak bearing pressures. Backings were still thick-wall. The 158 needed something better for the big-ends, however, and needle rollers were introduced there, either originally or as an early modification, noting that Jano may have used them in his 1937 V12. Needle rollers are particularly suitable for the variable angular velocity of big ends but, being uncaged, they are certainly not "friction-less".

Enzo Ferrari originated post-WW2 the marque which would in 1951 defeat the Alfa 159 – although not over a full season – and go on to its unique place in Grand Prix (and all other) racing. Colombo designed for him a 60^{0}V12 1.5 L engine and, around 1946, ran trials to decide whether to use plain or roller bearings. The plain contender was now the Vandervell "Thinwall" 3-layer (Copper-Lead-Indium) type which had been developed during WW2 for the 1944 Mark V version of the Napier Sabre H24 36.7 L aero-engine (631,632). This bearing combined the Gilman basis, with Napier's introduction of an electro-deposited 0.001 inch (0.025mm) thick lead plating to cover the grit/debris start-up problems more effectively, plus a diffusion of Indium to protect the lead from acids produced in the oil during service, with the advantages of the thin shell. This thin shell and the very-thin layer of actual bearing material minimised fatigue due to cyclical internal stresses as the material heated and cooled – the major part of the cooling still being by oil flow, of course. In the new Ferrari V12 the AL/D ratio was just under 0.5. Statements were published that the Vandervell bearings had shown "+10% output" (633) – compared to the roller alternative, it is presumed. Even if this figure was optimistic, ref. (594) stated that roller & ball friction is not necessarily much less than a plain bearing in the full-oil-film region (which would be considering roller/ball frictional interaction at the cage versus a low AL/D journal together in each case with the necessary oil pumping + scavenging powers). At any rate, weight and lifetime cost also being considerations, thinwall-type bearings were chosen for the V12 Ferrari and then remained in all subsequent Ferrari engines (with one partial exception 30 years later, which will be described below).

Every consistently-successful Grand Prix engine adopted the same basic type of thinwall multi-layer plain bearing up to the present day, apart from the Mercedes-Benz M196 (see below).

Interesting information on the plain Vandervell Thinwall bearing life in the 1954 Maserati 250F IL6 2.5 L engine is given in ref. (147), as follows:-

RPM limit	MPS m/s	Life of bearings	Relative $(MPS)^2$	Relative Distance*
7,200	18	5 races run by Moss' car, before overhaul, say 1,900 km.	Datum	Datum
7,600	19	2 races advised by Maserati, Say 1,200 km.	+11.4%	-37%
7.800	19.5	1 race advised by Maserati, Say 600 km. The usual works limit.	+17.4%	-68%

*Assuming practice covered the equivalent of20% race distance. In those days an engine would be run for the whole event, including usually 2 days of practice (unless it failed) but would probably have the valves reground before starting in a major race (147).

Mercedes-Benz roller bearings – and a rethink

The Mercedes-Benz W196, with M196 engine, was the Champion car in 1954 and 1955 (and in adapted 3 L form for the 300SLR sports-racing car also the 1955 champion in that category). It was the major exception in the 3rd Group use of plain bearings. Mercedes had both a "conservative-pioneering" policy and a reliability target – often achieved - of *all* 3 or 4 team cars finishing and the rolling bearing engine can withstand an oil supply interruption for some time, which might occur due to unexpectedly-high consumption and low tank level near the race end.

Nevertheless, when it was found by bench tests that the 300SLR engine had to be restricted 7% below its peak power RPM if the roller bearings were to finish the 1955 24 hours of Le Mans* a mostly plain bearing crank was schemed for the intended-but-later-cancelled 1956 sports-racing programme (468).This life limit was despite the M196 basic design having been improved – at great expense – from the pre-WW2 Mercedes split-races/ 1-piece crank by changing to solid races/developed Hirth-type built-up crank.

*In the 1955 Le Mans the Mercedes were actually withdrawn after 10 hours because of the 3rd team cars involvement in the spectator disaster of that year.

Ferrari mixed bearings

The Ferrari exception in the 3rd group of all- plain-bearing engines was the type 312B F12 3 L, Champion in 1975, 1977 and 1979. This began with 4 roller bearing main journals on a built-up crank but trouble with the latter led to a partial reversion with a solid crank having plain intermediates and the unsplit race rollers at each end.

Other non-"Car-of-the-Year" rolling bearing engines , rethinks and poor results

Porsche for their 1962 Grand Prix F8 1.5 L engine tried the same all-roller Hirth-crank pattern they had used in their previous racing engines but they settled on plain Copper-Lead bearings (635), obtaining a single win. This was, in effect, a re-run of the Ferrari tests of 1946.

Honda during 1965-1968, guided by Yoshio Nakamura, carried over their very-successful racing motor-cycle practice of roller & ball (R & B) bottom-ends to their 60^0V12 1.5 L and 90^0V12 3 L GP engines but had only isolated wins with each type. The 3 L was commented on as being relatively heavy. However, they did have great success with their 1966 IL4 1.0 L Formula 2 engine, also with all R & B.

In much more recent years, post the author's detailed review period but worth mentioning, the Peugeot 72^0V10 3 L GP engine of 2000 (at least) had roller bearing main journals, these having split races and a solid crank (1101, this describing the engine as taken over in 2001 by the Asia Motor Technologies company). The Peugeot GP engine programme, from 1994 to 2000, was not a success, the highest finishes totalling only four 2nd places in 7 years.

It was also reported (1102) that Toyota produced a development V10 GP engine with a *ceramic* roller main bearing crank which gained 20HP compared to plain bearings but the date was not identified. It was not raced due to regulation changes (probably the stepped life increases demanded beginning in 2003) .The gain might represent rather over 2%. Whereas the weight penalty would have been less than all-steel the cost would no doubt have been far above normal rollers.

Plain bearing material development in the 3rd Group

Plain bearing materials have moved to harder specifications in the last 2 decades. Whereas the Coventry Climax engines of 1961 -1965 used Vandervell VP2, virtually the same chemical composition as the Air Ministry DTD229 of the '30s with 74% Cu, 23% Pb, 1.5% Sn + controlled impurities + Indium, the developed VP10 specification had 78% Cu, 10% Pb, 10% Sn. This latter material is more truly called "Lead-Bronze" and, being harder, requires corresponding improvements in the 3 areas of:- Pin Hardness (300 Brinell); Oil Cleanliness; and Shaft Alignment. It can run to an average p = 82 MPa (12,000 psi), a 7-fold improvement over the century, and to a higher oil temperature: "above 125C" was quoted in 1997 (567). However, prior to 2003 the bearing life required would have been only 1 race + warm-up, about 400 km, an overhauled engine having been fitted after Qualification.

Crank diameter reduction

With bearing AL/D already reduced to a minimum, further advantage was taken in the '90s to reduce pin diameters as a proportion of stroke, even although RPMs had risen. This produces a square-law reduction in frictional power loss, as shown above. Vee 10 cranks were so "skinny" that they ran through a critical period at about 70% of peak power RPM (1095,255) – with electronic engine control systems a dwell on the critical speed could be avoided. That designers *were* prepared to take some risks to minimise journal (Diameter x Length) so as to reduce friction was illustrated in 1998 by 2 race retirements in 1998 of the Championship-winning Ilmor-Mercedes-Benz FO110G engine because of admitted main bearing failures.

A later report (1095) shows that BMW reduced their main journal and crank pin diameters for the 2002 season's P82 engine despite raised Red-line RPM, although it does not reveal by how much.

Oil in the post-WW2 period

Until about mid 1970 post-WW2 engines were lubricated with mineral oil modified with various additives to improve film strength and resist higher temperatures. A very-significant exception was the Mercedes-Benz M196 all-roller-bearing engine, where it was found that the latest Castrol R oil was the most suitable lubricant (468) (but this choice *may* have been forced to cope with the desmodromic valve gear).

In the early '70s oil made indirectly from crude petroleum was developed, derived from the chemical family of poly-alpha olefins (PAO) and generally called "synthetic". This had further significant quality advantages which enabled engines to be raced with less oil carried and smaller de-aeration and cooling systems (1100).

Some 15 years later another type of synthetic oil was available, originally developed for aero gas turbines, based on poly-ol esters. This reduced friction, hardly suffered aeration and withstood very high temperatures. It solved the problem of lubricating the highly turbocharged engines of 1983 - 1987 (1100). Mobil was supplier of this "dream oil" to Honda.

Some indication of continuing improvement in racing oils is given by 2 reports:-

- For the Italian GP in September 1993 Ayrton Senna's race engineer, Georgio Ascanelli, advised him that his Cosworth HB8 engine would benefit by 0.4% of power from a new oil (636);
- Mario Theissen stated in (1095) that over the 10 years of development of BMW F1 engines from 2000 to 2009 oil development had contributed + 4½% of power.

Note 18

Grand Prix engines Main Journal (MJ) and Crank-Pin (CP) Bearings (1): 1906 – 2000

Data sources as in Appendix 1. Notes (1) to (9) on next page, also *, ** and ***.

YEAR	ENGINE	CN (2)	MJN (2)	BEARING TYPE (3)				
				PLAIN			ROLLING (4)	
				WHITEMETAL (5)	COPPER-LEAD (6)	AL/D (7)	CRANK TYPE	
							SOLID,	BUILT-UP,
							SPLIT RACES (8)	SOLID RACES (9)
1906	Renault	4	3	● (10)				
1908	Mercedes	4	3	● (10)		1.59		
1911	FIAT	4	3	● (10)				
1912	Peugeot	4	5	● (10)				
1913	"	4	3	● CP				● MJ (B)
1914	Mercedes	4	5	●				
WW1								
1921	Duesenberg	8	3	● 2 MJ ● CP		0.94	● Rear MJ	
1922	FIAT	6	8				●	
1923	Sunbeam	6	8				●	
1924	Alfa Romeo	8	10				●	
1925	Delage	V12	7				●	
1926-27	"	8	9				●	
1928-31	Bugatti	8	5					● 3 MJ ●CP(C)*
1932-35	Alfa Romeo	8	10	●		0.5		**
1933	Maserati	8	5	● 3 Inter MJ ● CP			● 2 End MJ	
1935-36	Mercedes	8	5				●	
1934	Auto Union	V16	10		● (10)	0.32		
1935-36	"	V16	10		● MJ	"		● (CP) (H)
1937	Mercedes	8	9				●	
1938-39	"	V12	7				●	
WW2								
1947-51	Alfa Romeo	8	9		● MJ		● CP Needle Rollers	
All plain bearings were "thinwall" copper-lead from this date								
1949	Ferrari	V12	7		●	0.46		
1952-53	"	4	5		●	0.43		
1954-55	Mercedes	8	10					● (H)
1956 Onwards	All CoY except Ferrari 1975, 1977, 1979		CN per bank + 1		●	0.4 to 0.5		
1975,etc	Ferrari	F12	4		● CP ● 2 MJ		● 2 MJ***	

Notes to Table on P.8.

(1). Nearly all Gudgeon-Pins (GP) were steel running in plain hard bronze bearings, splash-lubricated, except that 1934 – 1937 Auto Unions had Needle Roller bearings, as did the 1954-1955 Mercedes-Benz. In engines post-WW2 GP bearings were copper-lead and since 1958 the lubrication will have been enhanced by crank-case oil jets used to cool the piston crowns.

(2). CN = Number of cylinders; MJN = Number of main Journals.

(3). Bearing type is same for MJ and CP unless shown otherwise.

(4). Usually Rollers, with a Ball-bearing for crank axial location.

(5). Bearings cast into thick bronze or steel shells except Duesenberg CP where whitemetal was cast directly into rods.

(6). "Thinwall" type beginning with Ferrari in 1947.

(7). AL = Axial Length; D = Diameter.

(8). Except those rolling bearings which could be threaded complete onto crank ends.

(9). Types of Built-Up cranks:-

- (B) = Bolted flanges;
- (C) = Taper and Key and/or Cotter-Pinned;
- (H) = Hirth proprietary type, with dogged faces and bolts. Post-WW2 with differentially-threaded bolts.

(10).These engines had cranks with no counter-weighting. Others counter-weighted.

*Bugatti: + 2 intermediate MJ which had split races with crowded rollers to avoid split cages.

**Alfa Romeo: 2 x 4 cylinder cranks bolted together between the 2 centre plain bearings.

***The Ferrari 312B had a roller bearing at each end of a solid crank and 2 intermediate plain main bearings.