1st Naturally-Aspirated Era (1NA)

1906 – 1923: 9 Racing Years

This Era can be sub-divided technically into 6 years pre-WW1 (1NA-1) and 3 years post-War (1NA -2), because of the technology changes which were invented and developed to improve aero-engines during that conflict, although they did not all appear immediately afterwards in Grand Prix racing-engine design.

Era 1NA-1: 1906 – 1914: 6 racing years

In this sub-Era, which was preceded by 11 years of city-to-city and Gordon Bennett pre-Grand Prix Naturally-Aspirated racing, all the winning engines were IL4* and had cast-iron or machined-steel pistons in cast-iron or fabricated-steel blocks with integral heads , breathing always through a single updraught carburetter. However, the sub-Era gave rise to very rapid changes in cylinder-head design.

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* In the 1907 French GP (FGP) 3 makes of IL8 engines appeared but none finished (835,940). Their day would come after WW1 development of multi-cylinder designs.

In the 1908 FGP 2 makes of IL6 raced but only 2 out of 6 cars finished in lowly places (940).

Eg. 1. 1906 Renault AK; 12,986cc; 90HP @ 1,200RPM See Figs. 1A, 1B, 1C, 1D.
Eg. 2. 1907 FIAT; 16,286cc; 130HP @ 1,600RPM See Fig. 2A
Eg.3. 1908 Mercedes; 13,533cc; 138HP @ 1,600RPM See Fig. 3A.

Era 1NA-1 opened in Cars-of-the-Year (CoY) with the side-valve (SV) Renault of Bore (B)/Stroke (S) = 166mm/150 = 1.11. This SV arrangement had been pioneered by the company in their Type A of 1902. The era continued with the 1907 FIAT of similar B/S = 180/160 = 1.13 having push-rod operated (crankcase camshaft location), 90^0 included angle (VIA), overhead-valves (OHV) (see Fig. 2A). This was followed by the 1908 Mercedes at B/S = 154.7/180 = 0.86 with push-rod operated vertical overhead-inlet-valves of *complex annular design* and side exhausts (see Fig. 3A).

1906 Renault details

The 1906 Renault had a particularly tortuous inlet system since the carburetter of their own design was placed on the opposite side to the valves (probably to keep any liquid petrol leak away from the exhaust manifold for safety and to avoid vapourisation locks) and also low down, so that it required a single tubular inlet manifold looping right over the engine. The total turning of the charge into the cylinder via siamesed inlet ports was therefore 9 right angles = 810^0 (2)(see Figs. 1A and 1B). Clearly, this arrangement could be and was improved rapidly as far as Volumetric Efficiency (EV) was concerned *but* it may be that all the inlet turbulence improved Combustion Efficiency (EC) by providing better mixing of fuel and air.

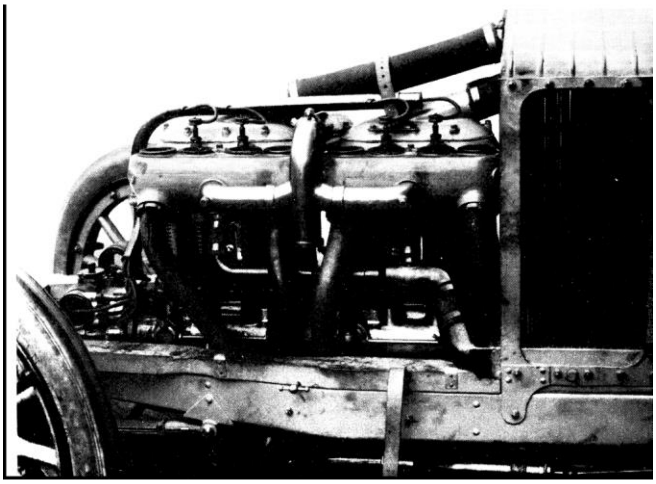


Fig. 1A
!906 Renault AK
IL4 166mm/150 = 1.107 12,986cc

Note the siamesed inlet ports and the radiator placed behind and above the engine for thermo-syphon cooling without a pump

DASO 2 p.51

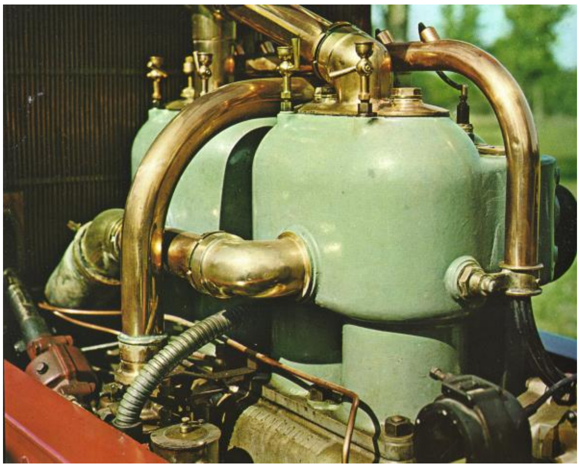


Fig. 1B

1907 Renault "*Grand Prix Replica*"

IL4 130mm/140 = 0.929 7,433cc

Included to show the "over-the-top"inlet manifold, as used on the type AK.

DASO 621 p.308

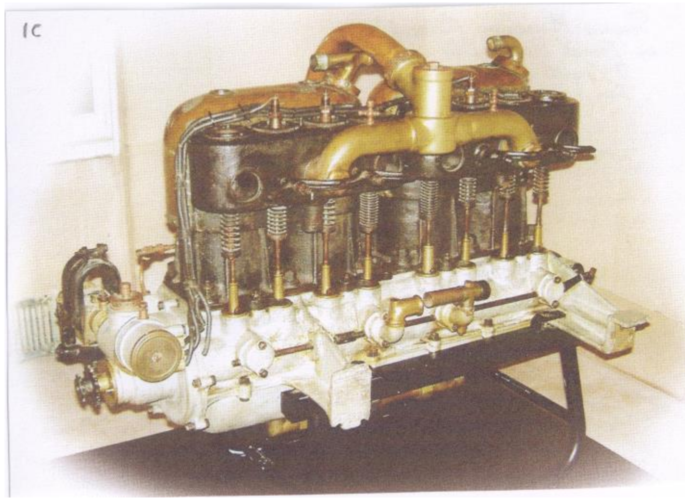


Fig. 1C

This is a Renault engine which is thought to be a 1906 Grand Prix unit later adapted for airship propulsion by cutting-away the cast iron water jackets opposite the valve chests and substituting screwed-on copper sheet fabrications to reduce weight.
Disassembly of this engine in the Science Museum showed the 3-bearing crank had 4-bolt big-ends.

DASO 1094

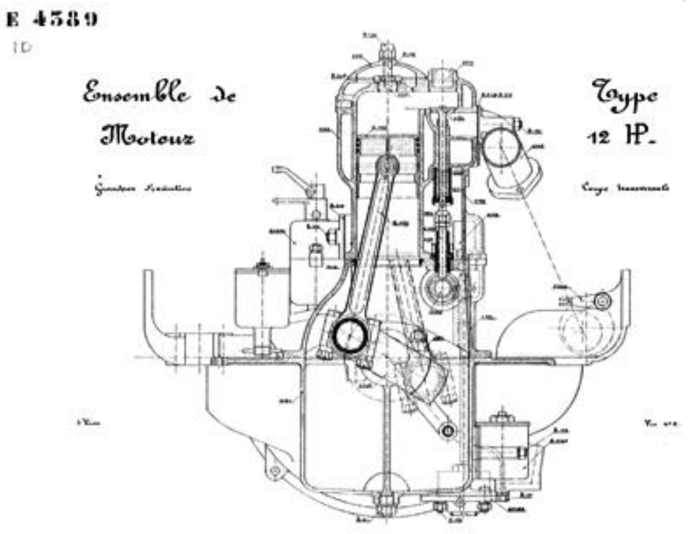


Fig. 1D

1911 Hispano-Suiza 12 HP

IL4 80mm/110 = 0.73 2,212cc

This section of a smaller Hispano is included to give some idea of the Renault internals, since it has many similar external features:- integral head and block; screwed caps above the valves to permit assembly, one containing the sparking plug; separate water-jacket caps (above the core-plugged cylinders); water-jacketted on only half the cylinder.

DASO 1064 p.17

Limited fuel in 1907

The 1907 FGP was interesting as a limited fuel consumption race, 30 Litres per 100 Kilometres being allowed. The winning FIAT beat this by 5% and the 2nd place Renault, identical to the 1906 winner, was only 1.6% slower on a consumption 13% better than prescribed. Possibly it could have won if it had been driven harder. It is surprising that this crude SV engine, 13 years before Harry Ricardo invented the turbulent head for this type, should have raced so closely to an OHV design of good cylinder head shape and the reason may be as speculated above concerning EC.

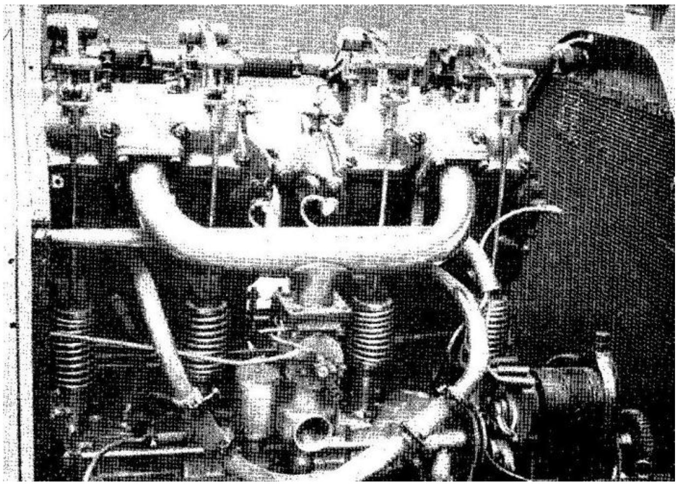
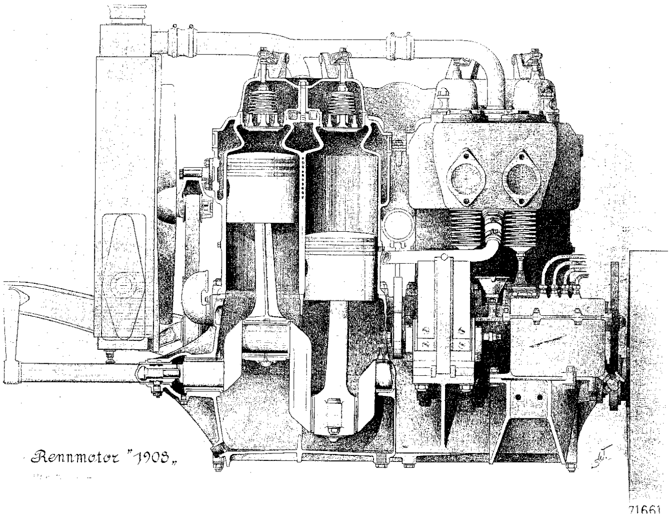


Fig. 2A
1907 FIAT GP
IL4 180mm/160 = 1.125 16,286cc

Note the "Push-Pull" rod system actuating the inclined, opposed, overhead valves. The sparking plugs were in the side of the combustion chambers.
DASO 2 p.52

Fig. 3A
Representing
1908 Mercedes GP
IL4 154.7mm/180 = 0.859 13,533cc

This section is of an engine enlarged to 175mm Bore(note the angled connecting-rod shanks) and 17,318cc but otherwise identical to the 1908 GP. Push-rod operated vertical overhead *annular* inlet valves and side exhausts,
DASO 468 p.26



<u>Eg. 4. 1912 Peugeot L76/EX1; 7,603cc; *140HP* @ 2,200RPM</u> See Figs. 4A, 4B, 4C.

A gap of 3 years occurred in the Grand Prix de l'Automobile Club de France (ACF) (usually named the French Grand Prix) after 1908, partly for economic reasons and partly because the ACF did not wish to see the previous two foreign successes extended, but for 1911 the AC de la Sarthe (ACS) at Le Mans proposed a race in its stead. They prescribed 4 cylinders of 110mm Bore and 200mm Stroke, i.e. B/S = 0.55 and Swept Volume (V) = 7.6 Litres. This was the 1st time in major races that both dimensions had been regulated.

<u>Peugeot L76/EX1</u>

A completely novel design to the ACS figures was prepared by a new group of men financed by Robert Peugeot separately from his main design office (and also to be built separately from the production factory) – the racing drivers Paul Zuccarelli, Georges Boillot and Jules Goux with the Swiss engineer Ernest Henri. This was type L76/EX1. For the 1st time a double row of inclined, opposed overhead valves was to be operated more-or-less-directly by overhead camshafts (DOHC for short)(see Fig. 4B) with a central sparking plug.

<u>L76 Valve Area</u>

To reduce inlet flow pressure drop and raise EV a very large valve head area (IVA)– 48% of Piston Area (PA) – was secured by using 2 inlet valves per cylinder (coupled with 2 exhausts - 4v/c) at VIA = 60^0 (see Fig. 4A).The valves were inserted from the bores of the then-conventional combined cast-iron block-cum-head and the guides fitted from above. The EC would have been affected adversely by the low cylinder inlet charge Mean Gas Velocity (MGV) of only 30 m/s (based on overall valve-head diameter), because fuel/air mixing would have been inadequate, having already begun badly at an over-large carburetter choke. The NA optimum-power MGV, according to modern experience, is about 75 m/s (246 ft/s) (<u>see Note 34</u>). To cope with the consequential engine inflexibility – inability to pull away cleanly from a low %age of peak speed – close-ratio gears had to be fitted in the 4 speed gearbox, the overall Bottom/Top ratio being only about 2 where 3½ would have been typical previously on *bolides* (4). However, the Dieppe circuit for the 1912 race had many long straights and was not very hilly so that gear-changing would not have been an excessive chore.

L76 valve overlap

The new Peugeot had another novelty for a 4-stroke engine of inlet /exhaust valve-timing overlap (4), although it is believed to have been only 9^0. Overlap for 4-strokes had been Patented by Percy Riley in 1903 (British Patent 14391 (447)) but whether Henri was aware of that is unknown. It is an aid to power generation, when the departure of the exhaust gases can leave a below-atmospheric cylinder pressure to assist inlet charge flow, but it also makes an engine less flexible.

L76 optimised B/S ratio

The major advantage of the new Peugeot design was probably that the prescribed B/S = 0.55 optimised a "Bottom-End" stress which was the highest then reliable for a long-distance race (Mean Piston Speed (MPS) = 2 x S x N of nearly 15 m/s, using a crank main bearing on each side of a throw (see Fig. 4C)) with a "Top-End" valve-gear stress which was the best that any OHV layout could tolerate in the 1906 – 1914 period (Bore Speed = B x N, a surrogate for Mean Valve Speed (MVS), being around 4 m/s (see Note 15)). This B/S ratio, so different from the GP engines of 1906 – 1908, was a recognition by the ACS of a development to low ratios in light car (Voiturette) racing where limited-piston-area formulae had been regulated during 1906 – 1908. These purely-theoretical rules, which assumed incorrectly that MPS would be limited by available materials to around 6 m/s, had been outflanked very successfully by Maurice Sizaire who simply made use of the "free stroke" to reduce his B/S from 1.09 in 1906 to 0.67 in 1907 and then to 0.4 in 1908, reaching 20 m/s MPS in the latter year, although probably only for short periods – the Voiturette race distance over which Sizaire & Naudin won in 1908 was only ¼ of the 1912 GP. This subject has been discussed more fully in Note 35. It is probably significant that this regulation lower B/S was proposed for their 1911 race by the provincial "non-professional" club at Le Mans rather than the "orthodox" Parisian ACF.

The L76 non-appearance at Le Mans

French industry politics prevented the appearance of the Peugeot L76 at the 1911 race of the ACS and, probably because of shortage of entries, they ran it as *Formule Libre*. The race was notable because a Bugatti Type 13 1.3 litre finished 2nd to the winning FIAT S61 10 litre. Although flagged-off at 10/12 of the 655 km distance, it had averaged 75% of the big car's speed on 13% of its capacity! This was something of a harbinger of what was to happen next in "real" Grand Prix racing.

The 1912 Grand Prix de l'ACF

When the ACF revived its own race in 1912 they also made it *Formule Libre*. One of the new Peugeot L76 7.6 litre cars won this race, somewhat luckily, in fairly well-matched competition with a FIAT S74 14.1 litre car, after ⅔ of each of the Peugeot and FIAT teams had suffered cracked petrol pipes – probably a consequence of 4 cylinder unbalanced secondary vibrations*.

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*Failures as quoted in ref. 4 – but (757) gives the non-technical explanation that the FIAT *leading at ¾ distance* hit a dog, the fuel tank was holed and the car was disqualified because it refuelled away from the pits. However, (940) based on ACF records states that it *was* a pipe fracture which caused the fuel loss and this seems decisive. Pity the historical analyst!

Comparison between L76 Peugeot and FIAT S74

The comparative engine factors for, what turned out to be, the 1st of a new breed of power units and the last of the "giants" are given below.

Italics indicate data not certain.

1912

Make	FIAT	Peugeot	Peugeot/FIAT
Type	1911 S74	1911 L76/EX1	
Data Sources	519	Eg. 4, see Appx. 1 appendix1.xlsx	
Configuration	IL4	IL4	
Bore (B)/Stroke (S)	150mm/200	110mm/200	
	= 0.75	= 0.55	

Table continued

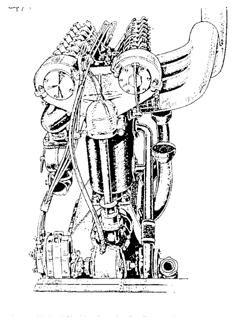
Make	FIAT	Peugeot	Peugeot/FIAT
Swept Volume (V) cc	14,137	7,603	53.8%
Valve gear	Single overhead Camshaft	Double overhead camshafts	
Valves/cylinder (v/c)	4 vertical	4 @ VIA = 60^0	
Power (P) HP	190	*140*	*73.7%*
@ N RPM	1,600	2,200	137.5%
BMEP @ P Bar	7.52	*7.49*	*Same*
@ Mean Piston Speed (MPS) m/s	10.67	14.67	137.5%
Bore x RPM BN m/s	4.00	4.03	Same
Car Weight Empty (WE) Kg	1,500	1,143	76.2%
Power/Weight ratio P/WE HP/Kg	0.127	0.122	*Same*
Frontal Area Sq.m	1.74	1.49	85.6%

The Italian engine was limited in RPM because its B/S ratio caused it to reach a “Top-End” valve-gear limit (BN at 4 m/s) before the “Bottom-End” limit (MPS at 15 m/s) which was exploited by the Peugeot (see Note 13 Parts 1 and 2 and also Note 15). Consequently the Peugeot from 54% of the FIAT’s swept volume produced 74% of its power. By this means the Power/Weight ratios of the two vehicles were the same. In the end the No.1 Peugeot driven by Georges Boillot beat the No. 2 FIAT driven by Louis Wagner by 1.6% after 1,536 km.

Of course, if the race had been run to a regulated swept volume of 7.6 litres as the ACS had planned originally for 1911, a type of rule by swept volume which became the most popular at varying capacities after its use for the 1914 Grand Prix, the Peugeot would have won very easily from a scaled-down 7.6 litre FIAT.

<u>The L76 contribution to engine design</u>

Ernest Henri is regarded as the “father” of the subsequently most popular method of arranging racing engine valves and their actuation, although of course many details have been improved since 1912, but, if he were to return today, he would recognise his general features at the “Top-End” even in many cheap production engines.



Top Fig. 4A

1912 Peugeot L76/EX1

IL4 110mm/200 = 0.550 7,603cc

Drawn from a poor quality photograph but showing that VIA = 60^0, and front shaft drive to camshafts.

DASO 938 p.42

Purported 1912 Peugeot camshaft housing, as seen in *La Vie Automobile.*

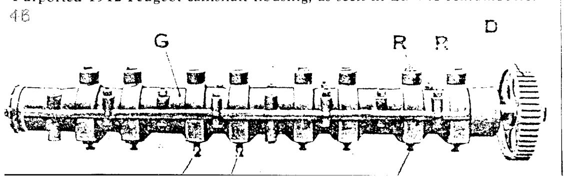


Fig. 4B

It is not certain that this is a 1912 Peugeot camshaft casing but it is unlikely to be anything else.

DASO 597A

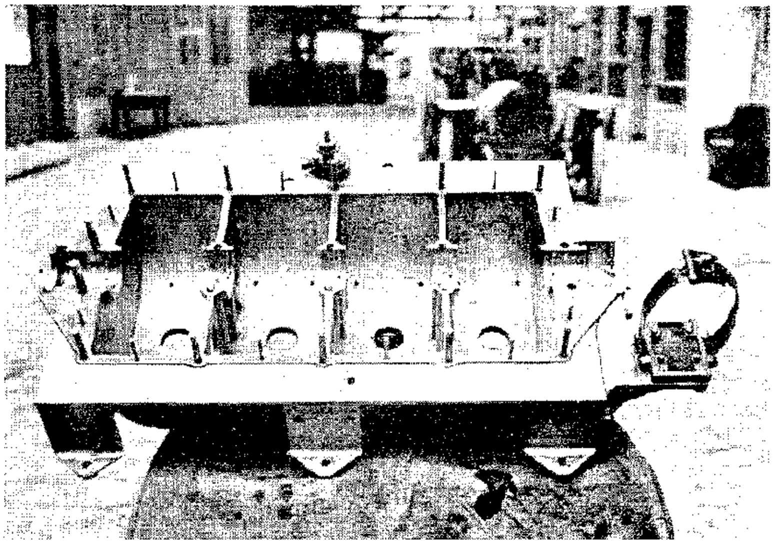


Fig. 4C

Lower half of L76 crankcase showing the 5 bottom halves of the 'sandwich' type main bearings.
DASO 4 plate 35

<u>Eg. 4. 1913 Peugeot L56/EX 3; 5,655cc; 115HP @ 2,500RPM</u> See Figs. 5A, 5B, 5C.

The 1912 Peugeot L76 averaged 28 L/100 km in winning the FGP (26) so that, when the 1913 rules prescribed a fuel consumption limited to 20 L /100 km, Henri was obliged to scale down his engine. He *may* have calculated that (20/28) x 7.6 L = 5.4 L but , in practice, used 5.6 L with B/S = 100mm/180 = 0.556, practically unchanged.

<u>"Bottom-End" improvements</u>

Substantial "Bottom-End" improvements were now included:-

- A counter-balanced crank (instead of un-balanced);
- 3 x ball-bearing crank journals (instead of 5 plain bearings), located in split circular diaphragms. The new crank was a 2-piece assembly, joined by tapers, keys and nuts, to make the centre ball-race possible – the alternative of splitting races and cages not then feasible;
- A " barrel" crankcase (rather than the previous case split and bolted-up on the crank axis). This enforced split plain big ends since the rods had to be inserted from above after the crank with assembled bearing diaphragms had been fed in from one end of the case, the nuts being on top for access (see Fig. 5C); these rod bearings were lubricated from splash-catching rings on the crank.
- Oil was scavenged from the crankcase to a separate tank for the 1st time (the "dry sump" system).

It seems as though Henri had tried-out his new Double Overhead Camshaft (DOHC) "Top-End" first and, being satisfied with that in 1912, then turned his creative energy to the "Bottom-End" in 1913. There was a detailed change to the valve tappet system, observable by different placement of the slider housings above the camshaft casings. The shafts were now driven by an all-spur-gear drive at the front instead of shaft-and-bevel-gear (see Fig. 5A compared with Fig. 4A).

<u>"Top-End" details (see Fig. 5B)</u>

The 5.6 L Grand Prix car was followed by a scaled-down 3 L car (L3/EX4) for the 1913 Coupe de l'Auto, which it won 2 months later. One of the latter type was dismantled in the Cunningham Museum in 1986 (597) and Fig. 5B was produced. The L56 apparently did not have the L-tappet return spring (to judge by a section of the 1915 Peugeot 90V8 aero-engine built up basically from 2 x L56 cylinder blocks). A feature of the cylinder head, integral with the block, is that to get the largest possible pair of inlet valves in the combustion chamber (IVA/PA increased from 0.48 to 0.54 in the GP engine) it was expanded somewhat from the bore – "Negative Squish" - which would have impaired the Combustion Efficiency.

More details of the 3 L Peugeot are given in Appendix 1 at SO5. Link to appendix1.xls

<u>1913 and 1907 limited fuel consumption race results compared</u>

The Peugeot type L56 won the 1913 FGP easily using 15% less fuel than the 20 L/100 km ration. Comparing the 1907 limited-consumption race with 1913, the winning FIAT had then achieved 4.6 tonne.km/L at 114 kph and the later Peugeot 7.7 at 116 kph on a tighter circuit, i.e. a 67%

improvement (both figures based on actual race consumption). Both engines were (near enough) hemispherically-headed inclined OHV, the 1913 unit possibly with a Compression Ratio (R) of 5 compared to 4 for the FIAT (worth 11%) . The FIAT had 2 v/c at VIA = 90^0 in a 180mm Bore with dual opposed side plug locations and the Peugeot 4 v/c at 60^0 in a 100mm Bore with a central plug. Presumably both engines were run on the weakest possible mixture and the largest possible ignition advance without knocking. The smaller Peugeot exhaust valves would have run cooler if seat widths were the same, as is probable, while the maximum flame travel was reduced to 68mm compared to 90mm, both of these features reducing the sensitivity to detonation (594 p.99); these things should have favoured lower fuel consumption.

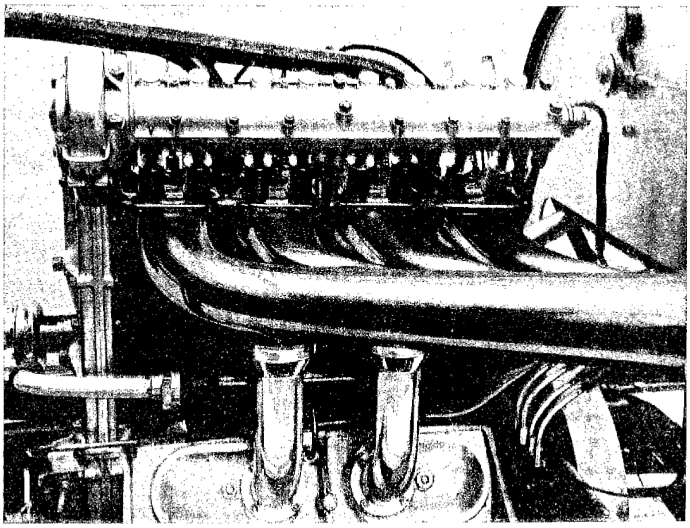


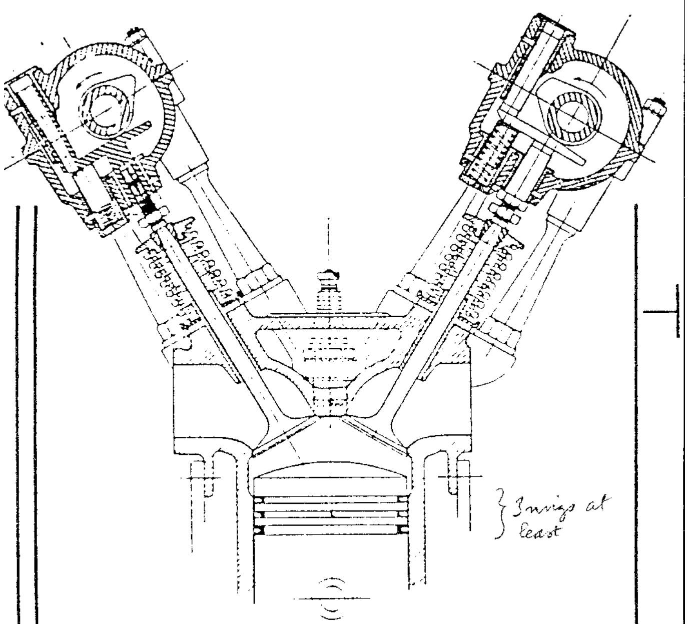
Fig. 5A
Representing

1913	Peugeot	L56/EX3
IL4	100mm/180 = 0.556	5,655cc

This is probably a photograph of the L3/EX4 3 Litre Coupe de l'Auto engine, which was identical in most details to the L56, apart from size. Note all-spur-gear-driven camshafts
DASO 294 plate 9

Fig. 5B

This is the 1913 L3 valve gear, drawn from a dismantled engine.
The L56 apparently did not have the L-tappet return spring.
DASO 597B



5B
Actual 1913 Peugeot valve gear, as drawn by James Toensing.

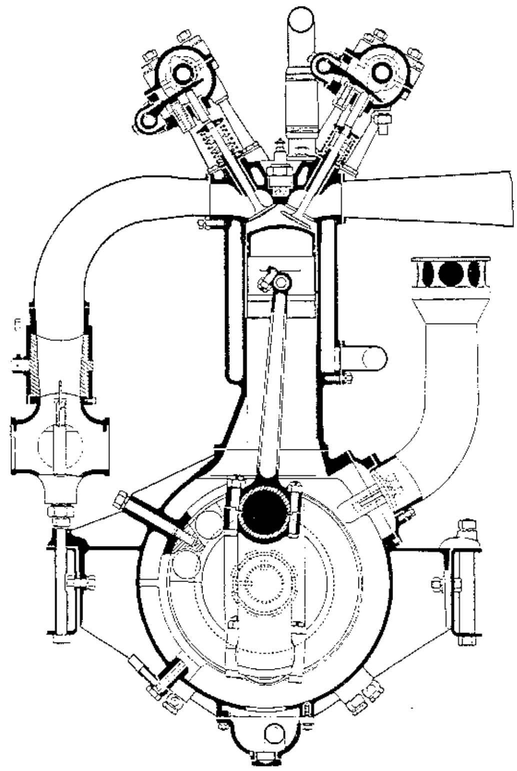


Fig. 5C
Representing L56 Bottom-end

This is actually a section of *either* a 1914 4.5 Litre Grand Prix Sunbeam, which had a new finger-follower valve gear;
or the 1914 Dario Resta 3.3 Litre TT Sunbeam which had the same system (DASO 24).
Whichever it is, the bottom-end can be taken as representative of the 1913 3 Litre Peugeot from which Coatalen had drawings made, and therefore also representing the L56.
Note one of the 4 radial bolts retaining the centre ball-bearing diaphragm.
DASO 711 p.12

<u>Delage refusal to copy Peugeot</u>

It is interesting, looking back on nearly a century of racing engines in which the great majority have used Henri's DOHC, that Michelat, the designer of the Delage type Y of 1913 which gave the Peugeots a run for their money over half of the FGP*, was not prepared to copy him then. He used 4 v/c but placed horizontally and operated by push-rods and rockers from 2 crankcase side camshafts (485).

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*Some reports suggest luck again came into this 2nd Peugeot FGP victory, on the grounds that a Delage which was leading by 1m 19s at 52% distance lost time on the next lap because its mechanic was run over while the car was stopping and he had to receive first aid from the driver. But (940) states that 2 tyres had been changed already on that lap and the car was halting to change a 3rd, so much time had been lost in any case.

<u>Eg. 6..1914 Mercedes M93654; 4,483cc; 104BHP @ 3,100RPM</u> See Fig. 6A and attached Power Curve.

The 1914 FGP was run for the 1st time under a maximum swept volume limit, of 4.5 L, to rules issued in September 1913 i.e. 10 months lead time to the race. Peugeots (of basically the same design as 1913 as regards the engine) then met and were badly beaten by a team of Daimler Motoren Gesellschaft (DMG) Mercedes, despite having the advantage of 4-wheel brakes vs. 2-wheel. The German firm entered 5 cars, the maximum permitted (they also brought to Lyon a spare car and a spare chassis!), and finished 1st, 2nd and 3rd, the first time that result had been achieved in *the* Grand Prix*, in a record FGP entry of 14 teams.

<u>M93654 general details</u>

Apart from 4 v/c and a B/S ratio of 0.564 (from 93mm/165), close to the winning 1912 and 1913 figures, the Mercedes engine had nothing in common with the previously-successful Henri Peugeots (his 1914 L45/EX5 engine was 92mm/168 = 0.548). The M93654** operated at higher MPSP (17 m/s) and BNP (4.8 m/s) than used before in long-distance racing (the 1914 FGP was over 753 km) despite having cast-iron pistons and only a Single Overhead Camshaft (SOHC) with rockers to operate the 4 v/c at VIA = 60^0. Inlet charge Mean Gas Velocity at Peak Power (MGVP) at 32 m/s*** was little different from the 1912-1913 Peugeots.

Material improvements

Clearly, material quality and design details had been improved greatly since Mercedes' 1908 FGP winner which had MPS = 10 m/s and BN = 4 m/s. The 1914 engines did need a new steel alloy for the counter-balanced crankshaft (468) and a new type of sparking plug with mica insulation (468) and 3 of them per cylinder (out of a boss provision for 4) to achieve the new speeds. It is also very likely that the exhaust valves were made of a new heat-resisting austenitic steel alloy just developed by Krupp (see Note 17).http://www.grandprixengines.co.uk/Note_17.pdf

It is known that the DMG tested the engines successfully with Al-alloy pistons but, on being given the choice, the drivers chose to have them in cast-iron (468).

Fabricated upperworks construction

The upperworks of this new Mercedes racing engine were made to the expensive welded steel sheet-plus -forgings fabricated pattern used by Daimler since they pioneered it for series production in the 1912 DF80 aero-engine. It was undoubtedly lighter than the cast-iron Peugeot (as was SOHC vs. DOHC) and this construction also enabled the water-cooling passages to be controlled to the designer's requirements instead of depending on the pattern-maker's ability and integrity (see Note 36).http://www.grandprixengines.co.uk/Note_36.pdf

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*The 1912 Sunbeam Coupe de l'Auto team had finished 1, 2, 3 in that race – as well as taking 3, 4, 5 in the concurrent FGP!

**A note on the Design Office designation system: M = Motor (engine); 93 = Bore in mm; 65 = Stroke of 165mm deleting the 1st number (no reason for this, it was just their policy!); 4 = No, of cylinders.

***At the correctly-measured Inlet Valve head Diameter (IVD) of 48mm (1061), not the typo of 43mm published in (49).

A crank detail

A detail showing the care put into the design was that the crank main journals (plain bearings) were increased in diameter gradually from 46mm at the nose, through 3 intermediate bearings, to the full-torque output end at 50mm (1061).

M93654 performance

A full 1914 works test chart for the type M93654 has been reproduced in facsimile in ref.(468) and is shown attached, the 1st such record known for a Grand Prix CoY engine, and this shows that it was run beyond the power peak – which was unusual for any engine up to that time. Christian Lautenschlager, the winning driver, reported bad vibration at the 3,500RPM limit of the tested range but curiously said the other engines did not suffer so much (468).

The Brake Mean Effective Pressure at Peak Power (BMPP) at 6.7 Bar was only average, despite burning 50/50 petrol/benzole (468) (probably another 1st for fuel type). Although running on this mixture the value of Compression Ratio (R) was apparently only 4.89 (1061: this figure was measured on Engine No. 5 of Order No. 209 as now preserved (correcting for a modern liner), which might be different from original), so perhaps DMG were being conservative here, as in piston material choice.

At Peak Power speed (NP) and Peak Power (PP), the Brake Specific Fuel Consumption (BSFC) was 265g/PS.Hr (0.592 lb/BHP.Hr) so that the Brake Thermal Efficiency (BThE), on the quoted fuel having 10,084 kg.cal/kg = 18,150 BTU/lb Lower Calorific Value + Latent Heat of 152 BTU/lb (added per Ricardo's method (242)) was therefore 24%. It can further be deduced that the Volumetric Efficiency (EV) was 75% (see Note 37). Note_37.pdf This was with a single updraught carburetter feeding 4 cylinders through 8 valves by a "Tortuous" inlet manifold.

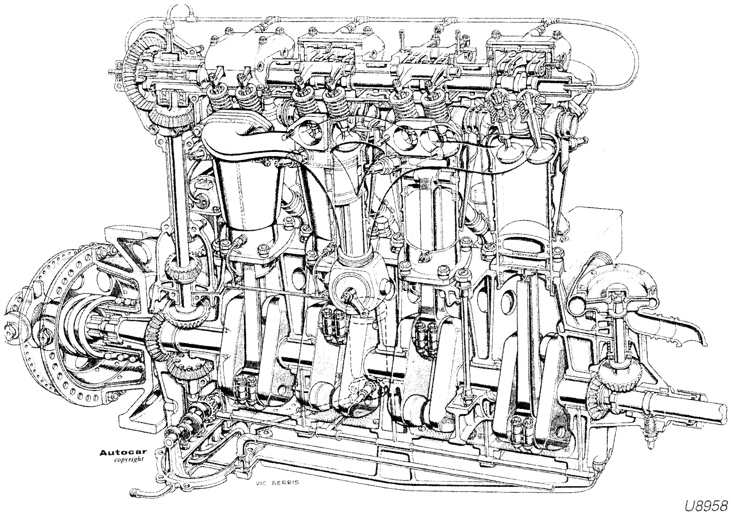


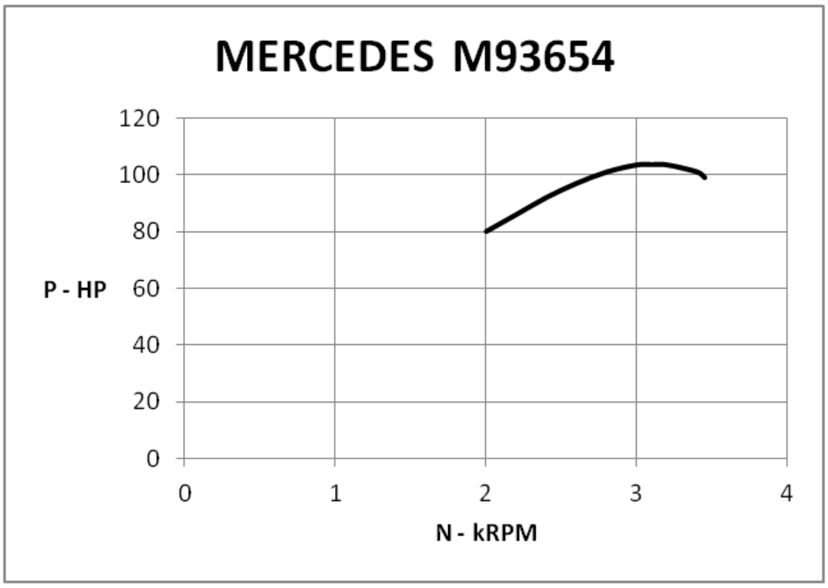
Fig. 6A
1914 Mercedes M93654
IL4 93mm/165 = 0.564 4,483cc

The 4-valve cylinder heads were cast separately and then screwed and welded onto the machined steel cylinder barrels.
Note the duplex webs supporting each main bearing. These were sandwiched between upper and lower crankcase halves.
DASO 49 p.720

POWER CURVES

Eg.	6			
DASO	468			
YEAR	1914			
Make	Mercedes			
Model	M93654			
Vcc	4483			
Ind. System	NA			
Confign.	IL4			
Bmm	93			
Smm	165			
	N	P	MPS	BMEP
	kRPM	HP	m/s	Bar
	2	80	11	7.98
	2.2	86	12.1	7.80
	2.4	92	13.2	7.65
	2.6	97	14.3	7.45
	2.8	101	15.4	7.20
	3	103.5	16.5	6.89
	3.1	103.6	17.05	6.67
	3.2	103.5	17.6	6.46
	3.4	101	18.7	5.93
	3.45	99	18.975	5.73

Powers as published were German PS and have been divided by 1.014 to convert to HP.



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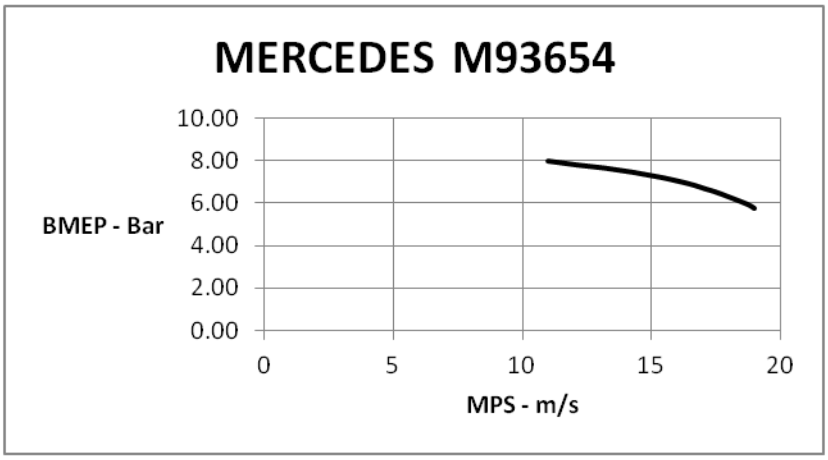

The end of the 1NA-1 era

The 1914 Grand Prix de l'ACF was run on 4 July, 6 days after the murder in Sarajevo of the heir to the Austro-Hungarian empire and his wife by an obsessed youth acting (it was suspected then and afterwards proved) with Serbian assistance. Unknown to all but a handful of people, on the day after the race the Austrian Emperor asked the German Kaiser for his support if Austria punished Serbia for the crime and then a major war broke out with Russia, who considered themselves protectors of their fellow-Slavs. This support was immediately promised by Kaiser Wilhelm II because it suited Germany's ambitions.

Thirty days after one of the finest motor races ever run, as a direct result of the Sarajevo crime and the Kaiser's promise, coupled with existing opposing treaties of international assistance arising from centuries of antagonisms, German troops invaded Belgium en route to attack a weak frontier of France. The integrity of Belgium had previously been guaranteed by Germany (Prussia), France and Great Britain. By this invasion Germany brought into war against her the whole of the British Empire and Commonwealth and by so doing ultimately lost.

The country whose cars had been all-victorious in the 1914 French Grand Prix thus turned the killing of two people into a world-wide tragedy for millions which, speaking only of the miniscule arena of motor racing, would mean that German teams would be excluded from that race for a decade after its post-war revival in 1921. Foreshadowing a greater tragedy, a full German return to classic Grand Prix racing would come only in 1934, starting no doubt with symbolic intent at the French Grand Prix. Adolf Hitler encouraged this return not just because he was a motor-racing enthusiast but also as a means of demonstrating national technical superiority (455). Thereby it helped to discourage foreign military opposition to his aggressive policy.

WW1 interruption and post-War Indianapolis

Aero-engine development forced by WW1 produced:-

- Better light alloys, especially for pistons (see Note 14); Link to Note 14
- Better heat-resisting alloys for exhaust valves (see Note 17); Link to Note 17
- Many multi-cylinder configurations, mainly to increase swept volume and therefore power without large increases in cylinder size (IL8, V8, V12, W12, 2 x IL8, V16, W18);
- Petrol with greater resistance to knocking (343);
- Experimental knowledge of Pressure-Charging.

The best Allied engines

On the Allied side the best water-cooled aero-engines were produced by designers who pre-War had concentrated mainly on high-quality long-life luxury cars – Henry Royce and Marc Birkigt. They both had some racing experience, Birkigt having won the 1910 Coupe de L'Auto but Rolls-Royce having dropped direct competition after winning the Tourist Trophy in 1906.

Royce had no hesitation in adopting Mercedes aero-type steel upperworks for his 60^0V12 engine (305)* but Birkigt's Al-alloy cylinder block with dry closed-end steel liners for his Hispano-Suiza 90^0V8 was novel (284). Both of these units were 2 v/c and SOHC per bank of cylinders. Peugeot and Peugeot-derived Sunbeam aero-engines based on immediately-pre-War motor-racing technology with Henri-type 4 v/c and DOHC were much less successful, being too complicated for service use and operating at too high stress levels.

The best Allied air-cooled engine was the rotary BR2 designed by Walter Bentley, who had some pre-War light car racing experience but nothing remotely like his aero engines, which he produced after un-enthusiastic work with French Clerget rotaries (688). He also introduced personally the Corbin Al-alloy piston to Rolls-Royce and Sunbeam (688), as described in Note 14. Note_14.pdf

Neither Rolls-Royce nor Hispano-Suiza engaged in motor-racing post-War but Bentley, of course, produced his own sports car whose engine he acknowledged was to some extent influenced by pre-War Mercedes practice (400).

Daimler

On the German side, Daimler continued for their major War output the same IL6 fabricated-steel technology which they had pioneered in 1912 for their Kaiserpreis aero-engine competition entry (468,637), retaining 2 v/c and SOHC for their earlier output then moving over to 4 v/c with SOHC. They were the first to adopt the Roots-type blower to pressure-charge a piston engine (after trying and rejecting piston and rotary-vane superchargers (468)). The system did not go into War service but they made use of this knowledge in their 1922 racing engines.

The presumed Bugatti influence post-WW1

Of WW1 aero-engines which never saw active service, the Bugatti 2 x IL8 side by side powerplant (which did not pass a US 50 hour Type Test (6,1046) because of crank torsional vibration breaking-up the coupling gears) is considered to have had some influence on post-War racing practice, not only on its designer (who had built an IL8 – or, at least, 2 x IL4 in tandem – in 1911 (308)), since Henri and the Duesenberg brothers, Frederick and August, were involved in its development in France and the USA respectively (2). The American pair had actually built their own IL8 in 1914 (6).

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*See also ref. (1097): *Eagle: Henry Royce's first aero engine;* D.S. Taulbut; Rolls-Royce Heritage Trust, Historical Series No. 43; 2011.

Eight-cylinder engines at Indianapolis in 1919

Whatever the inspiration or background experience, when racing resumed at Indianapolis in 1919, after a 2 year break and still under the 1915 300 cubic inches displacement (cid) rule (4.9 L), Ballot with Henri-designed cars and Duesenberg both entered with IL8 engines, the 1st at that track. The Ballot was essentially two of Henri's 1914 IL4 2.5 L engines joined in tandem by the same method as his 2-piece IL4 cranks, enclosing a 5th ball-bearing and with cranks at 90^0 which left only a secondary fore-and-aft rocking couple (372). This 2.5 L type had been built to the rule of the planned 1914 Coupe de L'Auto which had to be cancelled because of the war. A minor adjustment from its B/S = 75mm/140 = 0.536 for 2,474cc to 74/140 = 0.529 for 4,817cc was needed to meet the Indy rule. New 1919 features were:-

- Floating-bush big end bearings (see Note 18); http://www.grandprixengines.co.uk/Note_18.pdf
- Inverted-cup tappets (see Note 25B). http://www.grandprixengines.co.uk/Note_25B.pdf

The existence of the 2.5 L engine helps to explain how the 1919 Ballots were built in only 101 days (4). The 2.5 L itself had a major success in 1919, winning the Targa Florio.

The 1919 IL8 Duesenberg had only 3 main bearings

Ballot were the faster cars but their best finish was only 4th because smaller US-made wheels, fitted at the last moment to lower the gearing, broke on the other 2 cars (1050); Duesenberg got only one car half-ready and it failed. It may have been some consolation to Henri, but none to Ballot, that his 1914 GP car won the race again, having won it in the last pre-War 500 mile race of 1916.

Eight cylinder cars at Indianapolis in 1920

The next year, with Grand Prix racing still in abeyance in an impoverished Europe, both companies returned to Indianapolis with IL8 cars built to a new 183 cid (3 L) formula, basically similar to their 1919 engines. Again, Ballot were faster but a fuel-flow blockage from a broken-up cork gasket (6) at 95% distance when leading easily dropped their No. 1 car to finish 5th. Their No. 2 came 2nd, just ahead of the highest-placed hastily-finished Duesenberg. The winning IL4 Monroe at least had some pre-war Henri features.

The first eight cylinder win at Indianapolis

To conclude the story of the IL8 duels between Ballot and Duesenberg at Indianapolis, the 3 L versions met again in 1921 and again neither won – the solitary Ballot led but broke a con-rod (4) at 56% distance and a Duesenberg came 2nd. For the 1st time at Indy an IL8 won but it was a Frontenac designed by van Ranst, inspired by Ballot but with the very-important exception of a 1-piece crank having split plain journals (6).

Ballot and Duesenberg would meet again 2 months later in the first post-war French Grand Prix (see Eg. 7).

Post 1921 lack of European works cars at Indianapolis for 40 years

With the exceptions of participation by Mercedes and Bugatti in 1923 with lowly finishes, the entry of European works cars at Indianapolis then ceased*. The winning Maserati 8CTF 3 L of 1939-1940 was privately-owned. Ferrari did compete in 1952 with a Type 375 4.5 L but DNF. In 1961 Cooper entered a ⅔-sized mid-engined car and finished 9th. This heralded the Anglo-American Lotus-Ford mid-engined attack in 1963 and onward which revolutionised the US racing scene which, up to then, had been dominated by the conventional front-engined chassis**.

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*Correction: FIAT entered a type 805 2 L PC in 1925 which finished 10th.

**With the exception of Rosemeyer's Auto Union win in the 1937 Vanderbilt Cup.

The post-war return of Grand Prix racing
Era 1NA-2: 1921 – 1923: 3 years

Eg. 7. 1921 Duesenberg; 2,976cc; 114HP @ 4,250RPM See Fig. 7A.

Classic Grand Prix racing was not resumed until 1921, when the Duesenberg which won the French GP that year, run to the Indy 3 L rule, was the one and only US design to succeed in such events to date. It was an IL8, presumably one of their 1920 – 1921 Indy cars, which had a best result there of 2nd 2 months previously. The B/S = 2½inches (63.5mm)/4⅝inches (117.475mm) = 0.54 was similar to the 1912 – 1914 CoY engines The Compression Ratio (R) at 5.2 was also similar, although better petrol *should* have been available post-war (but possibly was *not* in France) and Al-alloy pistons were fitted which should also have permitted higher R (see Note 14). Note_14.pdf Possibly R was limited by the gasket of the detachable cylinder head (in cast iron, as was the block), this feature being adopted because the engine was intended as the prototype of a production unit. It was the 1st detachable head in the CoY series and it would be the last until the 1933 Maserati 8C-3000. The piston material was probably Harry Miller's "*Alloyanum*", developed by him just pre-war (see Note 14) Note_14.pdf and used in 1914 GP Peugeots successfully at Indianapolis in 1915 (2nd), 1916 (1st) and 1919 (1st).

Valve gear

Like the 1914 Mercedes the Duesenberg was SOHC but with the rockers opening 3 valves at VIA = 60^{0}, there being a pair of exhausts per cylinder – these cobalt-chrome alloy parts (711) needing most cooling – but only a single inlet. This provided IVA/PA = 0.36 so that MGVP reached 46 m/s*. The SOHC problem of "*where to put the sparking plug*" was met by having it at the inlet side of the combustion chamber – not the best position to avoid knocking and again perhaps a reason for the low R. The plugs were sparked by a Delco coil ignition system, a GP racing innovation since magnetos had been universal since 1906.

The valve gear was enclosed and therefore oil-cooled, the 1st use of this feature in CoY and which was usual thereafter (the 1908 Mercedes had enclosed OH inlet valve springs but the hotter side exhaust springs were exposed).

Improved cam design

A lack of knowledge of cam design restricted the useable RPM before spring failure in the Grand Prix but, later in 1921, Elbert Hall (who had helped Jesse Vincent to design the 1917 US “Liberty” aero engine) produced a new cam for Duesenberg after, probably, the 1st valve-gear rig tests. This raised safe RPM* sufficiently to increase power from 98HP to 114 (+16%)(6) at a Mean Valve Speed (MVSP) of 2.1 m/s. This compared with a pre-war MVSP in the range 1.2 to 1.4 (see Note 15).Note_15.pdf

Breathing, burning and performance

Still with only a single (Miller) carburetter per 4 cylinders and with “siamesed” inlet ports, nevertheless the inlet reduction of IVA/PA (and therefore increase in MGVP) compared to the pre-war Peugeot/Mercedes values around 0.54 will have helped – fortuitously or with insight – to produce a BMPP of 8.1 Bar* by a better product of Volumetric x Combustion Efficiencies (EV x EC) (see Note 34). Note_34.pdf This was 21% above the 1914 Mercedes on a similar level of R*. It also produced a flexible engine which was able to road-race successfully with only a 3-speed gearbox.

Plain bearing development

Only 3 main bearings supported the 8 crank throws, 2 plain and 1 rear ball, and perhaps because of this there was no advance on 1914 piston speed (approx. 17 m/s*). Duesenberg had had to cure plain whitemetal big-end bearing problems in their earlier IL8 engines (1919 4.9 L) at the higher RPM possible with the smaller stroke and, via rig-testing of a crank (probably a 1st) had moved to higher-pressure oil feed, around 100 psi (6), still using splash from the mains to feed the rod bearings via crank grooves but with the whitemetal cast directly into the tinned con-rods and only 1/32 inch (0.8mm) thick (711). This, by replacing thick babbit coatings in bronze shells, greatly improved the bearing cooling and trebled life (6). These improvements were incorporated into the 3 L engines (and began the move to the “*Thinwall*” bearing inserts developed subsequently in the USA by the Cleveland Graphite Bronze Co. and brought to England by Tony Vandervell in 1933 (68)(see also Note 18). http://www.grandprixengines.co.uk/Note_18.pdf

Hydraulic Brake advantage and *luck*

The 1st use of hydraulically-applied 4-wheel brakes in a Grand Prix and some *luck* in finishing with a stone-holed radiator from a very loose road surface assisted the Duesenberg win over their old rivals Ballot.

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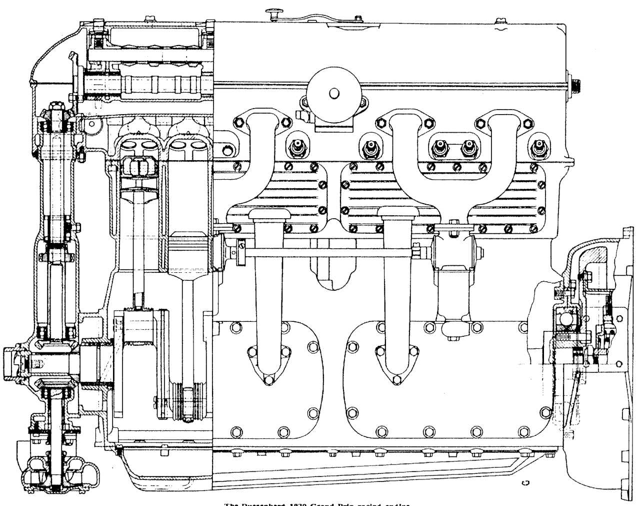
* The author admits cheating a little here to give performance figures from the engine as developed by the end of the 1921 season!

In the comparison with the 1914 Mercedes it must be borne in mind that, between different makes in this review, figures can rarely be near a scientific back-to-back comparison, although here the German power is from a published test chart.



The Duesenberg 1920 Grand Prix racing engine.

Fig. 7A

1921	Duesenberg	GP
IL8	2½’’/4⅝’’ = 0.541	181.6cu.in
	(63.5mm/117.475)	(2,976cc)

Note the detachable head and siamesed inlet ports.
Block and head were cast-iron.
DASO 6 p.150

Eg. 8. 1922 FIAT 404; 1,991cc; 112HP @ 5,000RPM See Figs. 8A, 8B.

The 1922 FIAT car type 804/engine type 404, built to another new swept volume rule of 2 L, won the French Grand Prix but only after the other two team cars had back axle failures (one leading to a fatal accident) of a welded-up construction which was too light (the *luck* element again, as so often in life – and death).

Engine configuration

The engine was IL6 simply because it was a design adapted to 2 L from a 1921 IL8 3 L (FIAT engine type 402), B/S being adjusted to 65mm/100 = 0.65 from 65mm/112 = 0.58, all other details being the same. It was the 1st 6 cylinder engine in GP CoY* and, apart from the near-copy Sunbeam of the following year, the last until 1957. Note that an IL6 can be in balance for both primary and secondary forces with only the 6th harmonic causing a slight vibration (372). However, there remains a problem of crank torsional resonance close to maximum RPM.

The fast but unsuccessful T802/402, inspired principally by Guilio Cappa (who had designed the Aquila Italiana racing car with *Al-alloy pistons* in 1912), had re-introduced 2 v/c (at VIA = 102^0) in a true hemispherical combustion chamber. With IVA/PA = 0.38 in the 2 L this produced MGVP = 44 m/s. It will be recollected that the 1907 FGP-winning FIAT (Eg. 2) had also been 2 v/c at VIA = 90^0 in that engine and so was their unsuccessful 1914 engine. Their S61 and S74 types in between had 4 vertical v/c – possibly Bugatti-inspired – while they had also tried 4 *inclined* v/c in an experimental IL4 3 L of 1920 which was their 1st DOHC design (type 401). Thus they had accumulated considerable varied "Top End" experience as a basis for the type 402.

Volumetric and Combustion Efficiencies and relative performance

Fig. 8A shows the peculiarity of the porting layout with 90^0 bends at both inlet and exhaust, which can only have reduced the Volumetric Efficiency. It is *just possible* that the inlet shape may have promoted some "*Tumble Swirl*" in the cylinder which would have assisted good combustion (see Note 26). Note 26.pdf Certainly, with a flattish piston crown, a central sparking plug and the movement to a more effective gas velocity the Combustion Efficiency was probably the highest yet in a Grand Prix engine, superior to the Henri designs.

Better petrol and Al-alloy pistons (Note 14.pdf) allowed R = 7. After allowing 12% for the difference in R compared with the 1921 Duesenberg, the Adjusted BMPP (= BMPA, see Appendix 1 Glossary) was 11% higher. In the FIAT case this was with all 6 cylinders breathing from one carburetter.

Mechanical features

Upperworks were steel fabrications, Mercedes pattern, which had been adopted for FIAT racing and aero engines immediately after the 1914 FGP (4).

However, the "Bottom End" was completely novel and, in fact, daring! By accepting *split races and cages* to permit assembly it was possible for the engine to have a 1-piece crank with 8 roller main bearing and roller big-ends. It ran at an MPSP of about 17 m/s, no advance on 1914 or 1921, the limit presumably still being the piston material Stress/Density ratio (see Note 13 Part 1).No doubt the intention of this costly and heavy bearing system was to raise the Mechanical Efficiency compared to the plain bearings of those years (see Note 18), contributing to the improved BMPP, and certainly any interruption of the oil supply could have been coped with better by rolling bearings for a time.

*See next page for this footnote.

Mechanical Features, continued

The piston ring design was also novel, being 3 packs of 2 rings each per piston so dimensioned in their grooves that the Al-alloy piston never touched the steel wall. The intention, presumably, was to reduce friction but, had the rings *not* been nearly choc in their grooves they would certainly have fluttered at low speed (see Note 13 Part 2).

Valve gear

The valves, opened by DOHC carried also in roller bearings (another 1st), had cam side thrust taken by finger followers (a feature which Coatalen had introduced into his 1914 Grand Prix Sunbeam engines and which FIAT may have spotted then). They were closed by triple springs, an insurance against frequent failures (25). The gear ran at MVSP = 2.1 m/s, which again was no advance over the Hall-cammed SOHC Duesenberg.

Setting a trend

The real advance of the FIAT T404 was in its superior BMPP with a cheaper DOHC 2 v/c layout than 4 v/c and it set a fashion which persisted in CoY engines and many others until 1968 – with the notable exceptions of pre-1931 Bugattis (4 examples), pre-WW2 Mercedes (4 examples) and the Australian Repcos (2 examples), which will be described later in this work.

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*Note from previous page. The 1908 French GP had seen a 1st appearance of 6 cylinder engines in this classic race, entered by Austin and Porthos. Two Austins finished out of a 3-car team but only 18th and 19th.

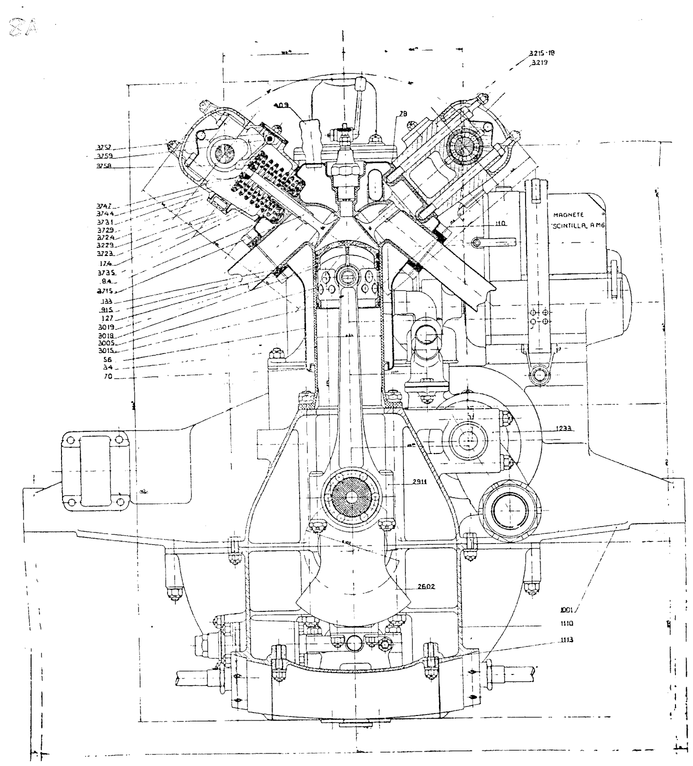
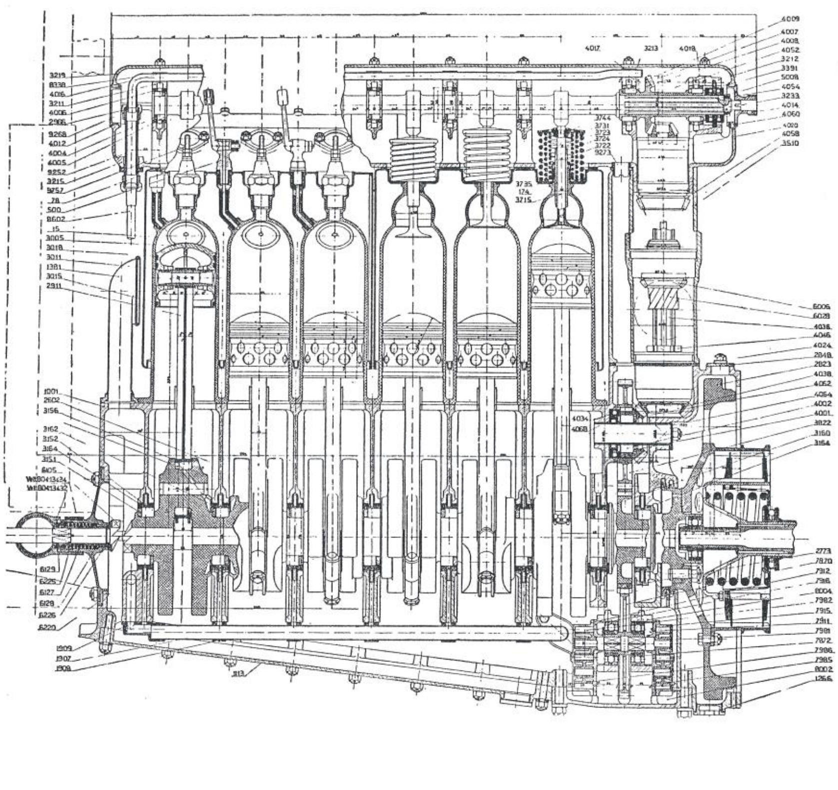


Fig. 8A
1922 FIAT 404
IL6 65mm/100 = 0.65 1,991cc

Note the roller bearing big end with split cage and outer race to permit a 1-piece crank.
Triple valve springs.

DASO 4 p.159

Fig. 8B
Note all-roller crank also requiring split cages and outer races on main bearings.
2 valves per cylinder.
DASO 4 p.160



Eg. 9. 1923 Sunbeam; 1,989cc; 108HP @ 5,000RPM See Fig. 9A.

The last Grand Prix CoY engine of the 1NA era in 1923 was a Sunbeam which was based largely on the FIAT type 404. Louis Coatalen, now Managing Director of the newish Sunbeam-Talbot-Darracq combine, improved on his reproduction in 1914 for the RAC Tourist Trophy of a 1913 3 L Peugeot EX4 light car “borrowed” surreptitiously for copying (1086) (the bore was enlarged 4.5% to meet the RAC 3.3 L rule) by hiring away from FIAT their designers Vincenzo Bertarione and Walter Becchia to produce his new car. They altered the B/S slightly to 67mm/94 = 0.71 from 0.65 and enlarged the inlet valves more than pro rata to 44.5mm (at VIA = 96^0 versus 40mm at 102^0) so that IVA/PA increased to 0.44 from 0.38 and MGVP fell back to 36 m/s – a retrograde step actually. Cam drive was changed from shaft-and-bevel to a train of spur gears.

After allowing for a trifle higher R (7.4 v. 7), BMPA fell back 5% nominally at 6% lower MPSP compared to its FIAT “prototype”, although these figures are well within the error margin of the data.

The battle in the French GP

The Sunbeams had a hard battle with ***the first pressure-charged cars to compete in the French GP***, the FIAT type 805 cars with type 405 IL8 engines, which were faster over a lap. Each member of the two teams led in turn but all the FIATs retired and all the Sunbeams finished, 1st, 2nd and 4th This was the last FGP won on petrol until 1958 (a Shell No.1 grade brought from England, a wise precaution since French petrol then was often of poor knock resistance). Callingham, the Shell representative at the race, stated that the exhaust valves were badly burnt at the end of the race (294). Presumably this was just before austenitic steel became available generally for these parts (see Note 17 also Note 32 regarding a query on the post-race condition of the engine).

This win was the last for a Grand Prix CoY NA engine until after 1951, and the last ever for a car with only a 3-forward-speed gearbox.

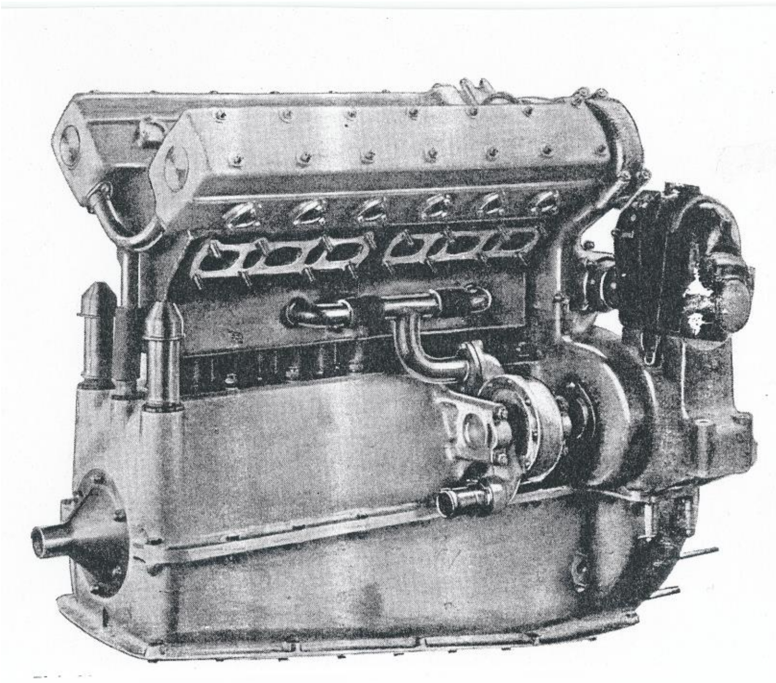


Fig. 9A
1923 Sunbeam GP
IL6 67mm/94 = 0.713 1,989cc

The magneto was mounted just behind the exhaust system, which would cause scorching when the engine was supercharged in 1924.
DASO 294 plate 16

The introduction of Pressure-Charging in 1923

As mentioned above the rival to the 1923 Sunbeam, the FIAT, had the 1st Pressure-Charged (PC) Grand Prix engine and this was made possible because the 2 L rules did not specify Naturally-Aspirated (NA) units – and, in fact, racing regulations did not acknowledge PC until 1938 – see Table 1 in the section 'The Sporting Limits'

However, FIAT’s choice of a particular type of mechanically-driven supercharger was their downfall in the race. Although Mercedes since 1922 had a Roots-type blower in both production and racing cars, FIAT preferred a Wittig eccentric-drum vane type (well illustrated in (764)). With some internal compression this would have been more efficient than the simple-displacement Roots, which was presumably its attraction to FIAT. It provided enough boost to produce 130HP (66) or 20% more than the Sunbeam but it seems that ingestion of grit as the road surface broke up in the race led to vane breakage whose debris then damaged the pressurised carburetter (768) and/or valve seats in all 3 engines.

Thus, as Pomeroy remarked happens frequently (32), the harbinger of a new era in racing engine design was defeated by a more reliable example of existing practice.

The FIAT type 405 IL8 engine with B/S = 60mm/87.5 = 0.69 was similar in *details* to their preceding 1922 winner. After the FGP debacle a Roots blower of greater boost and much greater tolerance to grit was substituted very quickly for the Wittig (765) and this gave FIAT a high-speed 1st and 2nd result in the Italian Grand Prix later in 1923. Like its predecessor and like the Mercedes system, the supercharger delivered pressurised air to a sealed carburetter. The fuel is presumed to have been petrol or petrol-benzole since an intercooler was fitted before charge entry into the inlet ports (66,765).

The limited gains from WW1 technical development up to 1923

The gains to engine technology generally during WW1 aero-engine development have been listed previously but how did these benefit motor racing engines in the early post-War years?

To the end of 1923 there had been no increase in MPSP compared to 1914 consequent upon Al-alloys replacing Fe-alloys for pistons.

Better petrol and the cooler crowns of these Al-alloy pistons (see Note 14) Note 14 did enable R to rise from about 5 to well over 7.

Better exhaust valve steel had not then reached automobile engines generally (see Note 17). Note 17

Perhaps the success of the Rolls-Royce, Hispano Suiza and the bulk of Daimler's aero-engine output *had* encouraged some designers to see that 2 v/c could be not merely *adequate* but *better* than cramming in valve area to get maximum IVA/PA, regardless of MGVP and combustion chamber shape - but this is drawing a very long bow. Certainly, Guilio Cappa of FIAT, who produced in 1921 the new type of 2-valve per cylinder engine, had wartime experience only with 4 v/c engines.

Multi cylinders post v. pre-War were the obvious change and it seems likely that the post-War designers *were* encouraged by the solution of problems from the proliferation of cylinders in Wartime configurations.

Only Daimler of the post-War competitors had learned anything about Pressure-Charging during the conflict and they *did* put this to use. The company were not acceptable for the premier race, the French GP, for many years post-1918 and did not achieve much with supercharging in other events up to the end of 1923. FIAT seem to have adopted Pressure-Charging with no reference to anyone else's experience.

It is probable that suppliers of egs. plugs, magnetos and oils will have learned much during 1914 – 1918 but details are lacking.

Addendum to 1NA era

A comparison of efficiencies, 1906 – 1923

(A "Short Glossary of Abbreviations" is given with the section **"An Overview of Performance"**)

It is shown in the preceding section on "**The General Design of Racing Piston Engines**" and the related Note 10 that:-

BMEP = 38 x MDR x ASE x [EV x EC x EM] Bar

at STP ambient conditions of 15C and 1.013 Bar

Taking out the effects of MDR and ASE, very much (but not wholly) dependent on fuel quality available at a date, the engine's combined efficiency "chargeable" to the designer is therefore:-

$$[EV \times EC \times EM] = \left(\frac{BMEP}{38 \times MDR \times ASE}\right)$$

The combined efficiency values are available in Appendix 1 by dividing Row 80 by 23.94 and multiplying by 100 to give a convenient %age.

Combined Efficiencies 1906 – 1923

The values of the combined efficiency [EV x EC x EM] for the CoY engines of the 1NA era are as follows:-

	1906	'07	'08	'12	'13	'14
Make	Renault	FIAT	Mercedes	Peugeot	Peugeot	Mercedes
CoY Eg.	1.	2.	3.	4.	5.	6.
[EV x EC x EM] %	31.9	27.6	33.2	43.6	39.0	37.0
	Average **30.9**			Average **39.9**		

	1921	'22	'23
Make	Duesenberg	FIAT	Sunbeam
CoY Eg.	7.	8.	9.
[EV x EC x EM] %	43.9	49.0	46.4
		Average **46.4**	

Inevitably, as cautioned elsewhere, there will be some scatter in these results arising from different standards in testing accuracy and reporting. However, the rising trend for the 3-year groups shown for the periods:- early races; later revival; post-WW1 is probably significant as designers "learned their trade".