2nd Naturally-Aspirated Era (2NA): 1952 – 1982: 31 years
Part 4, 1966 – 1982; Egs. 45 to 62

The 3L NA/1.5L PC Formula, 1966 – 1985

The CSI in late 1963 announced a new formula to run for 5 years, from the start of 1966 to the end of 1970, having a 3 Litre limit for NA engines and 1.5 Litre for PC, to run on 102RON Petrol the same as the existing formula. This was to power cars having a minimum weight of 500kg to the usual definition (i*ncluding* oil and water, *excluding* fuel or driver and with ballast prohibited).
Rotary (Wankel) and Gas Turbine engines were to be allowed, subject to calculation of suitable relative-rating methods.

This was a unique decision to **increase** the speed of Grand Prix cars, probably to prevent the very-large-engined Sports-Racing cars then being planned from beating the GP cars lap times.

The life of this Formula was extended in stages, eventually lasting to the end of 1985.

Although the 1.5L option was included in the hope that it could prolong by adaptation the use of the then-current 1.5L NA engines, the limitation to Petrol prevented this from being tried while only simple Mechanical Supercharging was considered. Not until Renault introduced to the Grand Prix arena in 1977 the application of TurboCharging-*plus*-intercooling would 1.5L PC be taken up and eventually surpass 3L NA in 1983. The latter date will be taken in its place as the start of the "**2nd Pressure-Charged Era**".

45. 1966 REPCO 620; 2,996 cc; 300 HP @ 8,000 RPM (See Figs. 45A & 45B)

Jack Brabham had been using the Climax FWMV engines in his cars and, after that company announced in early 1965 its forthcoming withdrawal from racing at the end of the year, needed to find a fresh supplier or retire from the front rank of racing. He considered that there were two possibilities not already pre-empted by his rivals, both based (more-or-less) on the suspended-production Buick/Oldsmobile F85 90V8 216 cid (3.53L) engine with its Al-alloy block and heads, which dated back to 1960 (112). This had been discarded by General Motors as too costly and it also had some service problems.

The REPCO redesign

The Australian REPCO concern, which had given help to Brabham's racing (his cars were entered as "REPCO-Brabham") and which made the "High-Power" cylinder head for Holdens and also racing spares amongst its bread-and-butter ordinary car parts, had decided in early 1964 to make its own 2.5L NA engine as a "drop-in" replacement for the ageing out-of-production Climax FPF IL4 2.5L engines raced under the Tasman Cup rules.
Frank Hallam, REPCO Chief engineer, and his designer Phil Irving (formerly designer for Vincent-HRD motorcycles and also author of "*Tuning for Speed*" (76) and "*Automobile Engine Tuning*" (342)) had chosen the F85 block for the new engine to save time and money. Brabham was consulted on the design which Irving carried out in the UK. A variety of European and Australian suppliers was used as well as REPCO. The 1st 2.5L unit, Type 620, ran in March 1965. REPCO planned to build a 4.3L Sports-Racing version later but the idea of a 3L GP engine was originally given a low priority. However, Irving worked out the 3L details in the summer of 1965 and the crank supplier Laystall in the UK put a suitable new crank in hand.

The TRACO redesign

Meanwhile, Brabham paid TRACO Engineering in California to develop the F85 as a 3L (this small company had been adapting and enlarging the F85 for Sports-Racing since 1963). New heads were fitted and 4 x 2-choke carburettors but push-rod OHV was retained. The engine gave only 250 HP and the project was dropped (839).

The REPCO Type 620 3L

The go-ahead for the REPCO 3L was given finally in September 1965, retaining the 620 designation (perhaps to mislead outsiders who knew of the 2.5L Tasman project?).
The new engine arrived in the UK in November and was fitted into a chassis built originally for the Climax FWMW F16 1.5L engine which had never been released. Brabham raced this BT19 on 1st January 1966 in the non-Championship S. African GP, led for 82% distance and then had the latest modified Lucas fuel injection system fail.

The new engine used the 90V8 F85 block suitably stripped of unwanted bosses and with un-necessary holes blanked. It was reinforced by a skeleton steel base plate (as had been done for Brabham's 2.2L Climax in 1958 (33).

The original F85 B/S of 3.5"/2.8" (88.9 mm/71.12) = 1.25 was changed in the 3L type 620 to 3.5"/2 3/8" (88.9/60.325) = 1.47. It retained the dry liners of the donor engine but had a flat crank, which was counter-weighted on each throw to eliminate block bending loads. The block choice and shorter Stroke required relatively-long con.-rods and available Daimler production parts were fitted. However, the bolts were too weak and had to be strengthened after a practice blow-up later on. The ratio CRL/S = 2.65 was the highest known to have been used in a CoY engine until the Ferrari 049 of 2000 at 2.68 (Eg. 85).

Irving designed new Al-alloy heads with chain-driven SOHC – the 1st in CoY since the 1936 Auto Union (Eg. 22) - operating 2 in-line cross-flow valves per cylinder via inverted-cup tappets in a wedge combustion chamber (it was the 1st in CoY to have in line inlet OHV since the 1930 Bugatti 35C). The inlet ports had 45^0downdraught. This layout was principally to raise RPM while keeping the width inside a dimension to suit existing chassis built for the IL4 FPF unit but it also reduced weight, lowered the Centre of Gravity and was cheaper than DOHC although the latter could have provided greater valve area. The type 620 3L had IVA/PA of only 0.22, the smallest such ratio of any CoY engine (excepting the 1908 Mercedes which had a unique annular valve).

The exhaust systems led from each bank separately to low-taper megaphones.

Type 620 Performance

BMPP was 11.2 Bar @ MPSP = 16.1 m/s with R = 10.5. MVSP = 3.1 m/s. VIA = 0, of course, and MGVP =74.5 m/s.

Racing results

The REPCO 620 was the only 3L engine ready-to-race on the first day of the new formula (although Ferrari *could* have been, with his long experience of V12 3L engines). This immediate start, stemming from the Spring 1964 inception as a 2.5L and despite the late decision to build the full-formula version but helped by its simple design, took Brabham ahead of his rivals from the middle of the season. Early problems had to be overcome which included 2 failures of the latest Lucas fuel injection distributor (841) and of a new type of Hewland gearbox (843). Jack Brabham then effectively won both the Championships with 4 consecutive victories, his first classic wins for 6 years. This was the first time that a driver-constructor had achieved such a feat in Grand Prix racing. It will almost certainly be the last time.

Enzo Ferrari helped Brabham's success by allowing his team manager (Eugenio Dragoni) to upset his No.1 driver (John Surtees, 1964 Champion) after he had won the 2nd 1966 Championship race with a DOHC development of the long-established type 250 SOHC 60V12 Sports-Racing engine, so that he then left the team*.

Brabham was backed up from July by a 2nd 3L team car driven by Denny Hulme who secured 2 seconds and 3 thirds.

Brabham's characteristically shrewd choice of engine soon gave him a genuine and reliable 300 HP (see Note 72) with a fuel consumption (in S. Africa) of 40Litres/100km (840) (about 1.7 tonne.km/Litre). Consequently only 150L weighing 108kg were needed for the typical race where his most complex rival, the BRM P75 FlatH16 needed 220L – an extra 50kg of fuel. His competitors claimed anything from 350 to 400 HP but *either* the loaded car weight was

disproportionate *or* the power was not available reliably until too late in the season (the last 3 races of 1966 were won in order by Ferrari 60V12 36 valve, Lotus 43-BRM FlatH16, and Cooper-60V12 Maserati) *or* it was an optimistic figure anyway – or some combination of all three caveats!

<u>Other people's mistakes</u>

Of course, it would be unusual for any victory to be won in any sphere of activity without the advantage of other people's mistakes, although frequently the victor forgets that and thereby incurs future disappointment when the oppositions' errors are corrected!

---

*Surtees joined the Cooper-Maserati team and finished 2nd in the Championship.

Fig. 45A
1960 GM Buick Special 216
Block donor for the REPCO 620
90V8 3.5"/2.8" = 1.25 215.5 cid
(88.9 mm/71.12) (3,532 cc)
The GM Oldsmobile F85 was the same but with some changes in the heads and pistons.
Note the cast-in iron liners in the Al-alloy block, which were retained in the REPCO 620.
DASO "Driving Force". J.Daniels. Haynes 2002.

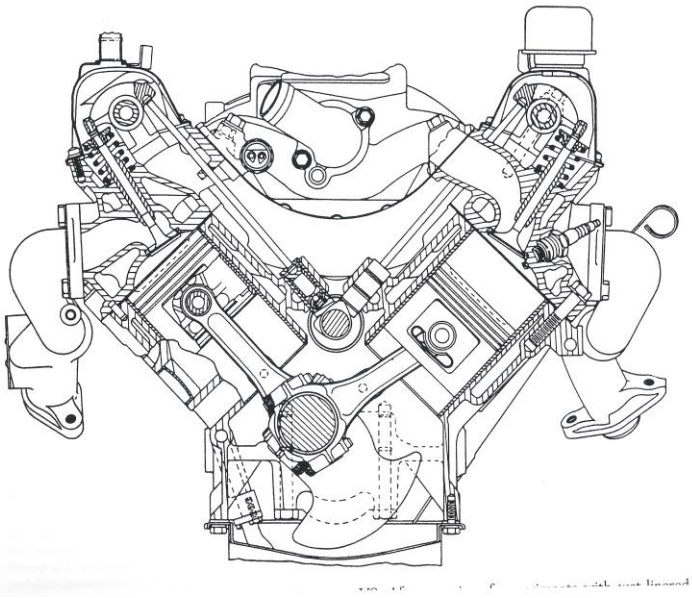
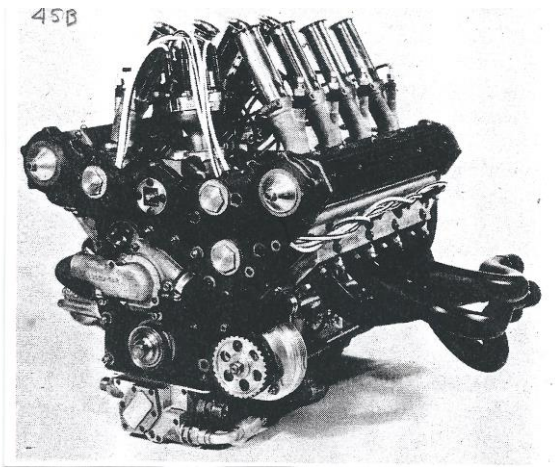


Fig. 45B
1966 REPCO 620
90V8 3.5"/2.375" = 1.474
(88.9 mm/60.325) 2,996 cc
Note the long inlet tracts to improve mid-RPM-range torque.
Chain-driven camshafts.
DASO 842



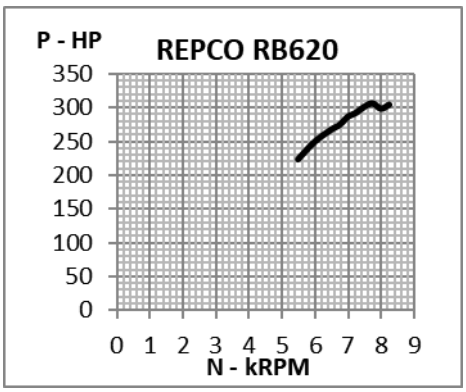
A late addition from Ref. DASO 1217 www.Repco Brabham Public Group Facebook advised by courtesy of Ron Rex, July 2019.

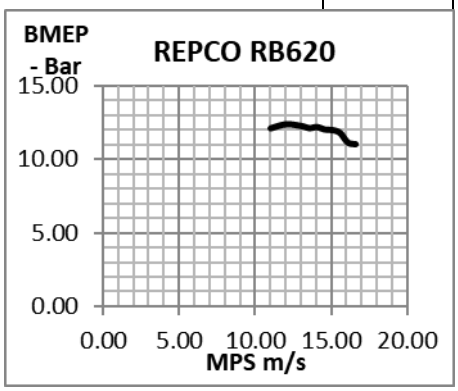
POWER CURVES

		N	P	MPS	BMEP
DASO	1217	kRPM	HP	m/s	Bar
YEAR	1966				
Make	REPCO	5.5	223	11.06	12.11
Model	RB620	6	249	12.07	12.40
		6.5	267	13.07	12.27
Vcc	2996	6.75	274	13.57	12.12
Ind. System	NA	7	286	14.08	12.20
Confign.	90V8	7.25	292	14.58	12.03
Bmm	88.9	7.5	301	15.08	11.99
Smm	60.325	7.75	306	15.58	11.79
		8	298	16.09	11.13
		8.25	304	16.59	11.01

REPCO ENGINE PARTS GROUP, ENGINE LABORATORY

Test Curve dated 17/11/66





Source advised by courtesy of Ron Rex.

46. 1967 REPCO 740; 2,996 cc; 330 HP @ 8,000 RPM (See Figs. 46A & 46B)

REPCO were encouraged by the 1966 successes to spend money on a major redesign of the 620 engine into the 740 for 1967, keeping the same B and S. They produced a new Australian-cast Al-alloy block with additional cross-bolts for the main bearing caps and wet liners, *plus* new SOHC flat-bottomed heads with "vertical" in-line valves. This was to run with a new piston having the combustion chamber in the crown, very similar to the 1964 Cosworth SCA Formula 2 unit. Same-side ports instead of the previous cross-flow were used to provide exhaust systems in the V8 valley. The inlets were again at 45^0 to the cylinder axis. This revised porting was somewhat surprising since, although it reduced the external drag of bulky outside pipes, the exhaust heat must have affected the Volumetric Efficiency. However, 10% more power than the 620 was claimed (330 HP) (see Note 73 comparing the SCA and 740).

The BT24 carrying the 740 engine was quoted as 9 MPH faster than the 1966 car (844) (see Note 74), some 2% more than would have been expected from +10% power but the new car was also 68 kg lighter (including 11 kg off the engine) and that would have reduced the rolling resistance.

1967 results

The complete new 3L engine was not ready until May 1967 (although mixed '66 bottom-end with '67 heads were raced before that in non-Championship events) and it was not developed to complete reliability until July. It suffered a broken con.-rod at Monaco and oil-scavenging failures at Spa. Thereafter only a blown gasket at Monza marred the finishing record.

After winning at Monaco with a 1966 car, the 740-powered cars then gained 3 wins and many podium places so that Denny Hulme won the Championship just ahead of his employer.

740 Reliability

Reliability was the decider for the Brabham-REPCO 740 team when faced from June onwards with the Lotus 49-Cosworth DFV 400 HP vehicles driven by two former World Champions. Jimmy Clark, in one of these, won 4 events but had troubles 5 times in 9 starts, while his team-mate Graham Hill retired 7 times

BT24 Speed

As already mentioned, however, the BT24 was no slow-coach, particularly when compared with the Lotus 49. On 7 grids it was an average of only 1.4% behind that car, which claimed a power advantage of 23% (not counting Spa, 3.2% slower while suffering the oil scavenging problem; or Monza only 0.3% slower because Brabham slipstreamed a new Ferrari with DFV-like HP!). A track 9% less than the L49 must have assisted its relative speed.

Post 1967 REPCO engine

The REPCO 740 was the last SOHC engine to power a CoY. A further redesign in 1968 of the head to DOHC with 4 v/c at VIA = 30^0 (influenced by the DFV as will be seen) produced competitive power but mechanical unreliability, particularly with the valve gear (60, p. 203). Brabham was then forced in 1969 to fit the commercially-available DFV.

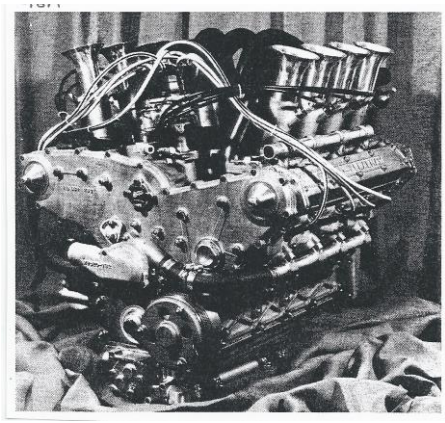


Fig. 46A
1967 REPCO 740
90V8 3.5"/2.375"
(88.9 mm/60.325)
= 1.474 2,996 cc
DASO 842

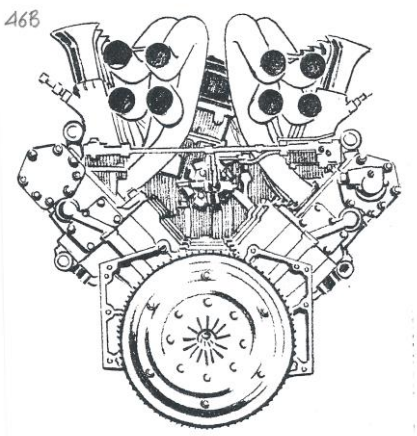


Fig. 46B
Showing the bulky inside-vee exhaust system.
DASO 951

Egs. 47 to 53 , 55, 58 and 60 to 62
are all Cosworth DFV as it powered 12 Drivers' Championships and 10 Constructors' Championships.
These are all described fully in "The Unique Cosworth Story".

Sample values of ECOM are as follows (based on "Best HP" (see Note 84)):-

1967 (Not CoY)	1971	1978	1983 (Not CoY)
57.5%	60.0%	57.4%	59.2%

---

54. 1975 Ferrari 312B (chassis 312T); 2,992 cc; 495 HP @ 12,200 RPM
56. 1976C Constructors' Championship
Ferrari 312B (chassis 312T2); 2,992 cc; 500 HP @ 12,200 RPM
57. 1977 Ferrari 312B (chassis 312T2); 2,992 cc; 510 HP @12,200 RPM
59. 1979 Ferrari 312B (chassis 312T4); 2,992 cc; 515 HP @ 12,300 RPM
(See Figs. 54A & 54B)

At the end of 1968, after 3 years of the new 3L Formula, Ferrari had won only 3 races with various 60V12 engines. At Monza in September 1967 they had introduced their 1st engine recognising the "4-valve Renaissance", having by then been able to consider the Weslake engine of that type since Monza in September 1966, the prototype Ford Cosworth Formula 2 FVA introduced in 1966 in English club events and the DFV on the Grand Prix circuits from mid-1967. In case anything had been overlooked in the new head design, Ferrari and all other rivals were then able to study a full description of the FVA, complete with cross section, in the March1968 "*Automobile Engineer*" (583), undoubtedly published at Ford's PR behest. No such report with detailed drawings and a power curve was ever made public for the DFV, only "*Motor*" (858, May 1967) and "*Autocar*" (175, June 1967) articles, excellent as they were!

Ferrari F12 engines

In late 1968 Mauro Forghieri, Ferrari's Chief Engineer, decided to produce a new engine to an F12 configuration including the "Narrow VIA, 4 v/c" architecture. The first example of this was the 2L type 212E of B/S = 65/50 = 1.30 which was used for European Sports-Racing hillclimbing in 1969 and powered the Champion that year. Its design was credited to Stefano Jacoponi, who left Ferrari at the end of 1969. It was not the 1st F12 from the company as the last 2 years of the 1.5L Formula had seen the type 1512, B/S = 56/50.4 = 1.11 unit driven usually by 2nd-line drivers. This was a wide-VIA 2 v/c design. It had shown more speed than the type 158 driven by Surtees in the last race of 1964 when Bandini had to slow down to allow the former to pass and win the Championship that year (793).

The advantage of the flat engine compared to other layouts is the lower Centre of Gravity. This reduces cornering weight transfer and so keeps the tyre operating points nearer to the maximum of the characteristic (Load v. Lateral Force) curve; also grip-reducing positive wheel camber changes are less The disadvantages are the cramped exhaust system and an engine with reduced beam stiffness, less able to take chassis loads.

The 312B

Working from the success of the 212E and, of course, from the unrivalled in-house knowledge of piston engines – Enzo Ferrari stated at his January 1969 Press Conference that he had by then brake-tested 154 different designs (544)! – Forghieri completed the 312B F12 Grand Prix engine by Monza in September 1969. The "B" stood for "Boxer", which implies a separate crank pin for each cylinder of an opposite pair so that the pistons move in and out in opposite directions. Actually the 312B was an "180^0 V12", avoiding the crankcase pumping of a true "Boxer" and being in primary and secondary balance with a flat crank.

Testing failures prevented the 312B from racing in 1969. These may have been associated with a crank problem. Originally the crank had 4 roller-main-bearings on a built-up crank and this did not prove reliable. The intermediates were then made plain to permit a 1-piece crank. This needed a rubber coupling between it and the clutch before the life was satisfactory (711).

Like the Maserati 250F1 of 1954 the cylinder liners were only wet over the top 27%. They were located at that length on a shoulder and were dry for the remaining length.

Internal details of the CoY 312Bs are not available but Ferrari had published a good section of the *1970* engine (see Fig. 54A on P. 8) (this was the last Ferrari racing engine section published until 2003 of the type 049 year 2000 unit; see Eg.85). The new design had B/S = 78.5/51.5 = 1.52 with VIA = 20^0. Angles from 10^0 to 35^0 had been tried experimentally without much difference being shown and the chosen 20^0 eased the exhaust outlet problem compared to 35^0. This was also helped by an "updraught" (relative to the bore plane) of 33^0. This was possibly the 1st use of this feature, which eased the exhaust turning required from the usual 90^0 (as in the DFV) to 57^0. The inlet downdraught was 55^0, substantially more than the DFV (35^0), again reducing turning loss.

The inlet port had *some* approach to the promotion of Tumble Swirl. The outer wall was about 12^0 non-orthogonal so that flow from that point would strike the opposite cylinder wall at 22^0, rather too much like an axial inlet port (see Note 26). The IVL/IVD ratio was 0.27, also rather low and IVA/PA = 0.31. R x VIA was 230^0. CRL/S = 2.14.

A small point was that the inverted-cup tappets had to surround the valve springs, as in earlier engines, since Woods-type tappets would have made the engine too broad.

1970 results

With development in 1970 the 312B secured 4 victories towards the end of the season and 2 more in early 1971 but then improved-DFV-powered cars came to the fore again (plus BRM V12s on 2 occasions) (see "The Unique Cosworth Story".

312B Crank Life

An interesting detail, already mentioned, was the use of only 4 main bearings to reduce friction and weight, those at the ends of the crank being roller where the races could be solid rings. When the same basic engine was adopted in 1971 for a Sports-Racing car (312PB), 7 bearings had to be used to give a crank life exceeding 24 hours (903). By 1976 Ferrari were "lifing" GP cranks at 15 hours (544) but still had both team cars' cranks fail at 10 hours accumulated life in that year's French race – Niki Lauda put this down to going too far to extract more power (the Paul Ricard circuit included the mile long Mistral straight to stress engines at full throttle). The Ford Cosworth engine by that date had *no* crank life limit (59).

312PB success

The 312PB was extremely successful, winning the 1972 World Sports-Car Championship with 10 wins from the 10 races contested (it was not entered at Le Mans).

Continuing development

The 312B engine, with one change of B/S to 80/49.6 = 1.61 in 1972, continued to be developed without major alterations until the end of 1980, an 11 year span. This was a contrast to earlier Ferrari policy, which tended to produce a major re-design each year. Its Championship successes came after Niki Lauda joined the team in 1974. An accident in 1976 prevented him from obtaining a hat-trick of Drivers' trophies over 1975 - 1977 but Ferrari did gain that as Constructor. In those three years the 312B powered 16 wins (one highly-contentious after James Hunt's disqualification from winning the British GP), 34% of the possible.

Funding by FIAT

Part of the mid-'70s success of Ferrari can be attributed to an inflow of funds from FIAT after that vast company bought a 40% shareholding in June 1969. Although the money was directed mostly towards increasing the output of road-going Ferraris, one early sign of the Turin firm's help with the racing activity (which remained under Enzo Ferrari's control) was the construction in 1971 of a private heavily-instrumented test track at Fiorano, very near the Maranello works. Although low in lap speed it reproduced several corners from the world's race-tracks. No competitor had anything like it.

1978 – 1979

The 312B was defeated, like all others, by the" Ground-Effect" Lotus type 79 in 1978 but regained both Championships in 1979 with 6 wins. The team drivers were actually 1st (Jody Scheckter) and 2nd (Gilles Villeneuve). This was due partly to its Michelin radial-ply tyres, competing against Goodyear cross-ply type. They had been first fitted by Ferrari the previous year and their first win had also been the 1st for the Michelin radial in Grand Prix racing. Altogether in 1978 Ferrari had gained 5 wins. Michelin, long before having pioneered the new construction for road use, had 1st supplied it for Grand Prix racing to the Renault 1.5L TurboCharged (TC) car in July 1977.

1980 collapse

The 312B F12 engine was particularly unsuited to the new "Ground-Effect" era, which employed an "inverted-wing" underbody, because the cylinder heads were where rising floors were needed to provide diffusing channels to the rear of the chassis. With this handicap against DFV V8-engined cars and also with Ferrari now concentrating on following Renault to a V6 1.5L TC engine (it first raced in 1981), there was a very-unsuccessful 312B season in 1980. No wins and the previous year's Champion, Scheckter, was 23rd on the grid at the last race!

312B compared with the DFV

The 312B can be compared with its perennial rival, the Ford Cosworth DFV, in the same Ferrari Championship year of 1979.

Engine	312B	DFV	312B v. DFV
B/S	80/49.6 = 1.613	85.6742/64.77 = 1.323	
PP HP	515	480	+ 7.3%
@ NP RPM	12,300	10,800	+13.9%
		Typical	
BMPP Bar	12.52	13.31	- 5.9%
@ MPSP m/s	20.34	23.32	- 12.8%
ECOM	52.8%	55.6%	
BNP m/s	16.4	15.4	+6.5%
W kg	160	≈ 160	
PP/W HP/kg	3.2	≈ 3	Same, near enough

The performance improvement of the 312B from 1970 to 1980 was from 460 HP to 515, a 12% rise in 11 seasons. This compares with the DFV achieving 405 HP to 535 (Judd-tuned) = +32% in 16½ seasons (see Note 84).

The overall results for the 312B were37 wins in 158 races, 23.4% of the possible. The DFV gained 154 wins in 236 races = 65.3%.

The DFV was capable of taking full chassis loads between front and back, which the 312B was not. The former therefore provided a chassis advantage, not in weight since there was a minimum rule but in stiffer construction.

When “Ground Effect” was introduced post-1976 the DFV fitted naturally into that chassis type, unlike the 312B. It is interesting that the Alfa Romeo concern, which supplied to Brabham a Chiti-designed F12 very similar to the 312B, was prepared to redesign their engine in 1979 into a 60V12 so as to accommodate chassis diffusers. Ferrari won the 1979 Championship without taking that expensive step but, as stated, faded from the podium completely in 1980.

Fig. 54A
Representing
1975 Ferrari 312B
F12 (180V12) 80/49.6 = 1.613 2,992 cc
This is a section of the 1970 version of the 312B, with B/S = 78.5/51.5 = 1.524, 2,991 cc
but details are believed to be similar.
Note the “updraught” exhaust ports and non-orthogonal inlet ports.
The cylinder liners were only in contact with water for 27% of their length.
DASO 124 p.192

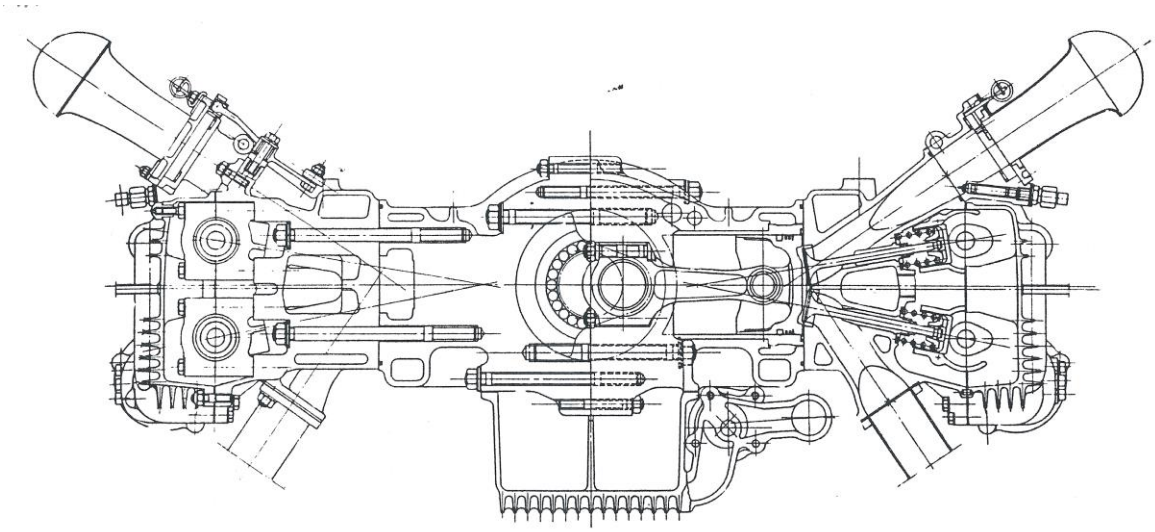
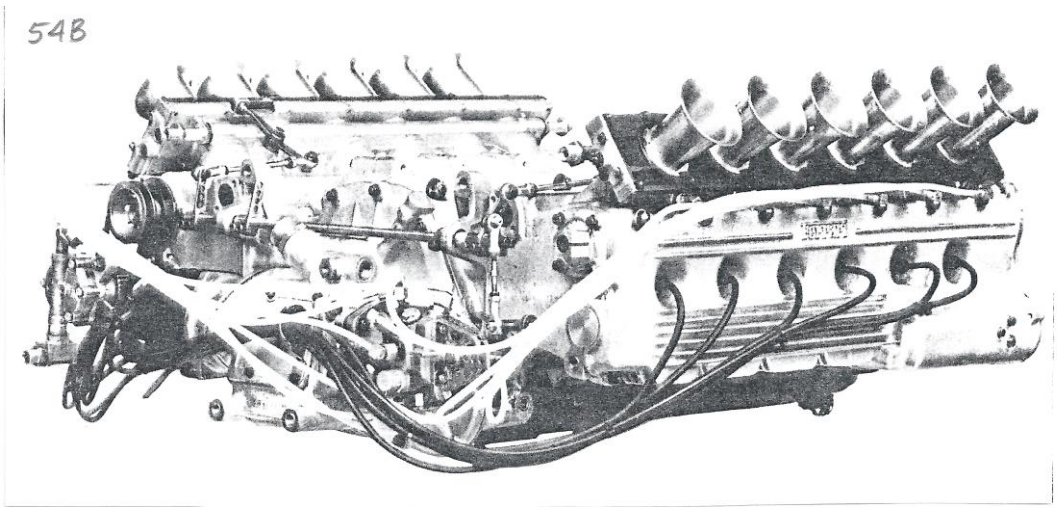


Fig. 54B
Stated to be a 1974 version of the 312B
DASO 22 p.115



Summary of advances in the 2nd NA Era

During the 31 years of the 2nd NA Era, from 1952 to 1982, the performance of CoY engines, all with "**Individual and Tuned inlet and exhaust systems**" rose as tabled below.

Year	1952	1982	+31 years
Engine	Ferrari 500	Ford Cosworth (Judd-tuned)	
	2 v/c @ 58^0	4 v/c @ 32^0	
BMPP Bar	**11.3**	**13.7**	**+21%**
MPSP m/s	**18.7**	**24.4**	**+30%**
S mm	78	64.77	
100/S mm	**1.28**	**1.54**	**+20%**
Consequently			
PP/V HP/L	**91**	**172**	**+89%**
(See "The General Design of Racing Piston Engines", p.3)			(1.21 x 1.30 x 1.20 = 1.89)
ECOM	**47%**	**57%**	**+10%points**

The biggest single contributor to this near-doubling of Volume-Specific Power was the "Duckworth Architecture" part of the "4-Valve Renaissance" (as the late Brian Lovell termed it) in 1967, using narrow VIA this time around and including Duckworth's introduction of deliberate "Barrel Turbulence" (aka "Tumble Swirl").