3rd Naturally-Aspirated Era (3NA) 1989 – 2000 (end of review): 12 years.

Part 1, 1989 – 1994; Egs. 72 to 78

The 3.5 Litre Formula

Introduction

The last entry of a Naturally-Aspirated engine under the 3L NA/1.5L PC Formula of 1966, as extended, was for the 1985 Austrian GP where Martin Brundle failed to qualify a single Tyrrell 012-Cosworth DFY (the redesigned DFV, see Note 88). He was 27th with a time 14% (12 seconds) greater than Pole, the grid cut-off being 26 starters. All other entries were 1.5L TurboCharged with up to twice the HP.

In 1985 the FIA had found a good home for the large number of DFV engines now uncompetitive in GPs by creating Formula 3000 to supersede Formula 2 as a drivers' stepping-stone to the premier formula (see Note 88) and for 1986 FISA actually banned NA engines from Grand Prix racing. Presumably this was a safety measure because of the large speed differential.

However, the major formula revisions of October 1986 re-permitted NA from then onward at 3.5L capacity (with TC restricted in various ways and to be banned post-1988). Cosworth were the leading company supplying 3.5L NA in 1987 (type DFZ) and 1988 (type DFR) and the details of these units and how they fared against the leading TC engines are described in Note 95.

Meanwhile, in the 2 years lead time until 3.5L NA should become the only GP formula, all major engine competitors began completely new designs. Cosworth chose a 75V8 (type HB) with B/S = 94/63 = 1.49; Ferrari a 65V12 (chassis type 639, engine 034) with B/S = 84/52.6 = 1.6, building respectively on their many years' experience with these numbers of cylinders although with novel Vee angles. Honda and Renault both broke new ground for Grand Prix engines with V10 configurations. Clearly they believed that this would be a successful compromise between the higher power but high fuel consumption, weight and size of a 12-cylinder *versus* the better figures for the last 3 parameters but lower power of an 8-cylinder. Consideration of useful torque range will also have come into the choice*

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*. Porsche preWW2 probably designed the 1st V10 automobile racing engine. BMW had also considered it in the early '80s – see Note 98. Alfa Romeo actually pre-dated Honda and Renault with a V10 3.5L engine in 1985, intended for a Racing-Sports car series which did not flourish. Although built and F1 was contemplated it was not raced in GPs.

The Honda V10 was unveiled at the October 1987 Tokyo Motor Show (727), suggesting an early 1987 main design start, with a 1st track test in an adapted McLaren MP4/4 chassis at Silverstone in July 1988 (941). Renault seem to have started at about the same time on a 3.5L engine (configuration unknown) since (922) reports that it was 14 months after initiation when, in June 1988, a supply deal was signed with Williams. A Renault 67V10 was shown publically in July 1988 (941) and it began track-testing in an adapted Williams FW12 in September 1988 (941), i.e. 2 or 3 months after Honda. Whether these two V10 choices were entirely independent or some project ideas "leaked" from one firm to the other or, indeed, whether they had both taken a lead from Alfa Romeo, it is clearly impossible to say. It has been reported that Honda went to the expense of testing V12, V10 and V8 engines before choosing the middle option (1005).

Having become accustomed in the TC era to the use of specially-uprated engines for Qualification ("Q" rating) the teams still wished to have the same advantage with their new 3.5L engines. This was done with higher RPM than that which would survive a race – the Q units were, of course, exchanged before the race for fresh engines with the necessary life. Drivers *did* sometimes switch off the rev-limiter now fitted *briefly* in the race in order to overtake, hoping that there was a safety margin – and were sometimes disappointed about that!

The fuel companies continued to supply special brews which met the 102RON rule in the calibration engine but exceeded it in the racing engines, until this was stopped by the authorities in mid-1992. Honda reported later that this cost 5% of power (69).

It must be assumed that powers quoted, from whatever source, were those at Q rating.

Increased funding from TV-stimulated sponsorship

One reason why the expense of two sets of engines could be accepted was the steadily-increasing flow of funds to the teams coming from TV-stimulated sponsorship. This permitted the 3rd NA Era to see a large increase in the number of modifications introduced during the season, after much testing between races on the bench and at special track sessions *plus* a large scale of redesign between seasons. A much-accelerated rate of engine Power/Weight advance with time resulted, as is shown on Figure O3 in the Overview of Performance section. Eventually at the end of this review (2000 Ferrari 049) this parameter for CoY engines at 7.5 HP/kg equalled the best figure of the TC era (Honda RA166E*). Post this review the non-CoY 2005 prototype BMW P85 greatly exceeded it with 11.4 HP/kg (see Note 112).

Regrettably, from the point of view of the technical observer, this increase in competitive technical activity led also to much greater secrecy over engine specifications. Even the Bore and Stroke were often withheld. Some 1989 Renault data had not been confirmed officially in 2013!

Approximate figures from the best outside sources are shown in Appendix 1 and this section by *italics* or shaded cells.

It must be hoped that in time it will be possible to provide better analyses as the facts are revealed.

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*Which did not include the weight of the intercoolers.

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72. 1989 Honda RA109E; 3,496 cc; *610 HP @13,000 RPM* (See Figs. 72A & 72B)

As already mentioned, Honda began design of an 80V10 3.5L NA engine early in 1987 (while still developing their final two TC engines – an indication of the resources which they could deploy). The V10 configuration which they chose has a *natural* Vee angle for equal firing intervals of 72^0 with a 5-throw crank (2 x 360^0/10). It is then balanced vertically and horizontally but has an engine-speed rocking couple. It may be that Honda, whose 80V6 TC engine was rough but nevertheless extremely successful, thought that they could carry the same Vee angle into the V10 and accept the couple. Comparing the two engines:-

Type	RA168E	RA108E (574)
B/S	79/50.8 = 1.555	89/56.2 = 1.584
		(*assuming same B/S as RA109E)*

It is not known if this new NA unit was track-tested but, in any case, vibration ***was*** found to be unacceptable (717). A redesign to 72^0 Vee angle was produced with a balance shaft (727) in the vee, running at engine-speed in the opposite direction to the crank and having weights at each end on opposite sides, to counter the inherent rocking couple. This was a heavy solution, reported as an engine weight of 150 kg (where the contemporary Renault RS01 67V10, believed *not* to have a balance shaft, was quoted at 141 kg (574). If the redesign was the first unit track-tested, 8 months were available until the 1st 1989 race of the new formula, a most unusual situation. During this time and at a late date (February 1989) Honda changed the camshaft drive from rear belt drive (62) (see Fig. 72A - a novelty for them but a feature of all Renault racing engines since the CH1 of 1972 and carried over to *their* new V10, although all front-drive) to gear-drive to provide more accurate valve control. This would allow safe use of a higher compression ratio.

Engine supply

This RA109E was exclusive and free-of-charge to McLaren (Lotus having been dropped after their poor showing with the 1988 RA168E). Honda supplied sufficient engines to McLaren to equip 2 test teams with dedicated cars, one in Europe and the other in Japan, driving for 100 days in the year, as well as 10 engines per race. Altogether they claimed officially to have built 300 V10 engines (948)! This may have meant in practice the number of times a fewer quantity of units had been overhauled with replacement of short-life parts.

Several versions were introduced during the season.

All-Titanium-alloy valves

While the engine (which had a thin-wall cast-steel block (938)) was to the now-conventional "Duckworth architecture" of 4 v/c at a narrow included angle (VIA = 40^0 or less) and DOHC per bank, it had a very-significant improvement in the 1st GP engine use of **all-Ti-alloy-valves, for exhaust as well as inlet**, to increase the RPM capability of the "Top-end".

The benefit stemmed from the reduced density of the alloy, which was Ti6Al4V (originating in US military aerospace development), being only about 60% of typical valve-steel alloys. Its availability for NA exhausts, at least for a few hours racing life, was crucial since otherwise using it to prevent *inlet* valve bounce would simply have transferred the RPM "Top-end" limit to the other side. Teams, with the increased funds mentioned in the Introduction, were prepared readily to scrap even these more expensive valves after only one race, just as they did already with pistons and valve-springs.

Honda had incorporated all-Ti-alloy valves successfully in their 1983 90V4 motorcycle racing engines (eg. RS850R, B/S = 75/48.6 = 1.54 (97)) but the advent of TC with its higher exhaust temperature had prevented their use previously at the exhaust location.

The valve-return system remained steel wire coil springs (CVRS).

Higher MPSP and BNP compared to RA168E

Compared to the TC RA168E, the NA RA109E with cooler pistons was able to run at MPSP = 24.4 m/s instead of 21.2 (+15% or + 32% stress). With lower-density valves the BNP factor for the RA109E was 19.3 m/s vs. 16.5 (+17% or +37% stress). The BNP gain suggests that about ¾ of the reciprocating mass (or its equivalent for the rocking-finger cam-followers used by Honda) had Ti-alloy in place of steel (see Note 13 Part III).

Piston-ring Flutter

The higher engine speed produced Maximum Piston Deceleration (MPD) about 20% higher than the RA168E and the consequences of this for piston-ring flutter have been enlarged upon in Note 13 Part II, where it was hypothesised that the RA109E rings operated successfully above their natural frequency – Postscript 2 to that Note later confirmed this (from Peugeot 1994 engine experience). Nevertheless, a wet race in Canada was lost when the engine apparently dropped frequently onto the ring-resonance RPM.

RA109E Performance

With the best analysis that can be deduced, lacking official data, it seems that BMPP was only *12 Bar* and ECOM *about 50%.* This compares with the last CoY engine of the 2NA era, the 1982 Cosworth DFV, at BMPP = 13.7 Bar (14% higher) and ECOM = 57% at the same MPSP of 24.4 m/s.

This may indicate excessive friction. The factor [NP x $(MPSP)^2$], which has been shown to be significant in determining Friction + Pumping Mean Effective Pressure (FPMEP) (see Note 99) which was 77.10^5 RPM.$(m/s)^2$ in the Honda was 15% higher than the 67.10^5 of the DFV.

1989 Results

With two World Champion drivers, Alain Prost and Ayrton Senna, the Honda RA109E-powered McLaren MP4/5 had no difficulty in securing the 1989 Drivers' Championship for the former and also the Constructors' title. These were obtained with 10 wins from 16 races – although Prost and Senna fought each other tooth-and-nail, eventually collided in Japan and threw away that race.

The McLaren-Honda team failed to win 6 races but in 4 cases (including Japan) the result had been influenced by collisions involving Senna. On one occasion (Canada) there were technical failures involving both cars (engine and chassis). Once (Hungary) they were beaten fair-and-square by a Ferrari type 640.

The Honda V10 victory was in a season where the competition from 7 other new 3.5L NA engines comprised:-

2 x V12s:- Ferrari 640/036* with 3 wins;
Chrysler-Lamborghini 3512* with none;
Another V10:-Renault RS1 with 2 wins;
4 x V8s:- Ford-Cosworth HB2 with 1 win (after the Senna-Prost collision and subsequent disqualification of Senna for a push-restart and not rejoining the track at the point that he left it);
Judd EV;
Tickford*-Judd;
Yamaha OX88*.

Of course, there were dramatic differences in the budgets of these engine builders and the Tickford-Judd never raced.

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*These engines had 5 valves per cylinder (3 inlet, 2 exhaust). This system had been pioneered by Yamaha in its 1985 FZ750 racing motorcycle and used in its 1986 OX66 2L Formula 2 engine with some success. The Tickford adaptation of a Judd engine actually had 3 OHC per bank, the extra camshaft operating the 3rd inlet – one can only be amazed that they thought such complexity could yield a worthwhile improvement!

The Alfa Romeo 1035, which did not reach a GP chassis, (see Note 98) had also been tried with 5 v/c in 1985 – 1986. Whether this preceded or followed Yamaha is unknown. Works drawings show that the 3rd inlet had a different (smaller) valve angle so that it could be operated by the same camshaft as the other pair (DASO 1111).

The Ferrari Semi-Automatic Gearbox

The 1989 Ferrari 640 was the 1st car to have a Semi-Automatic Gearbox (SAGB) in which servo power to change gears was controlled electronically by two finger-tip-operated “paddles” under the steering wheel (one for “up” and the second on the other side for “down”). With this arrangement and system, an innovation of John Barnard, the driver did not have to remove his hand from the wheel as in the conventional manual boxes. With 7 forward speeds in the Ferrari gearbox and the reduced change-time this enabled the V12 engine to be optimised for peak power.

To the amazement of all, especially its driver Nigel Mansell, it won its 1st race (in Argentina)! It did have to have a change of steering wheel in that race to re-instate the necessary electrical contacts.

Apart from the quicker gear-change and greater car control advantages of the new system, the necessary electronic control of RPM gave the possibility for the 1st time of avoiding an overspeed after a premature down-change. Consequently the safety-clearance margin for valve-bounce between head and piston could be removed and the compression ratio raised. It is not certain that this feature was available to Ferrari initially but it was developed by McLaren and Honda by 1992

Naturally all other teams had to copy Ferrari but a SAGB was McLaren’s responsibility and this was not developed to race reliably until 1992. Williams introduced their version of the SAGB in 1991 and suffered a number of failures in the early part of the season. Ferrari themselves were not without such troubles.

Renault's *"Distribution Pneumatique"*

Another significant feature of 1989 was the further application by Renault of their *"Distribution Pneumatique*" (DP) to the RS1 V10 3.5L (Honda, when they adopted the idea, named it with greater clarity "Pneumatic Valve Control System" (PVRS)).

In this system, which was patented by Jean-Pierre Boudy in 1984 (474), the usual steel-wire coil springs, which have a frequency depending on geometry at which the moving part of the coil goes into resonance with RPM ("surge") and so generates extra life-reducing stresses, are replaced by the compression of air or gas (usually Nitrogen) in a concentric static cylinder by a piston attached to the valve (see Note 15).

A large increase in Mean Valve Speed (MVS) is thereby made possible (*and* a weight reduction at the top of the engine).

In its original 1986 application to their EF15 1.5L 90V6 TC engine Renault claimed an increase of nearly 14% from DP (927), i.e. BNP = 16.7 m/s vs. 14.7 for steel coil springs

DP was intended by Renault to overcome the valve-gear disadvantage of their early TC units having an excessive B/S ratio (of 2.01) but it was not actually ready to be applied until after that figure had been reduced to 1.62. No useful competitive gain was secured by it in 1986 or in 1989 when first fitted to the new V10 3.5L NA engine for the new Formula. The 2 race wins in 1989 which were obtained by the Williams FW13/Renault RS1 came after McLaren retirements in Canada and Australia.

Figs. 72A & 72B are given on P.6.

Fig. 72A
1988 Honda Prototype V10
This shows the rear belt-drive to the camshafts which was track-tested but not raced.
DASO 948 p.102

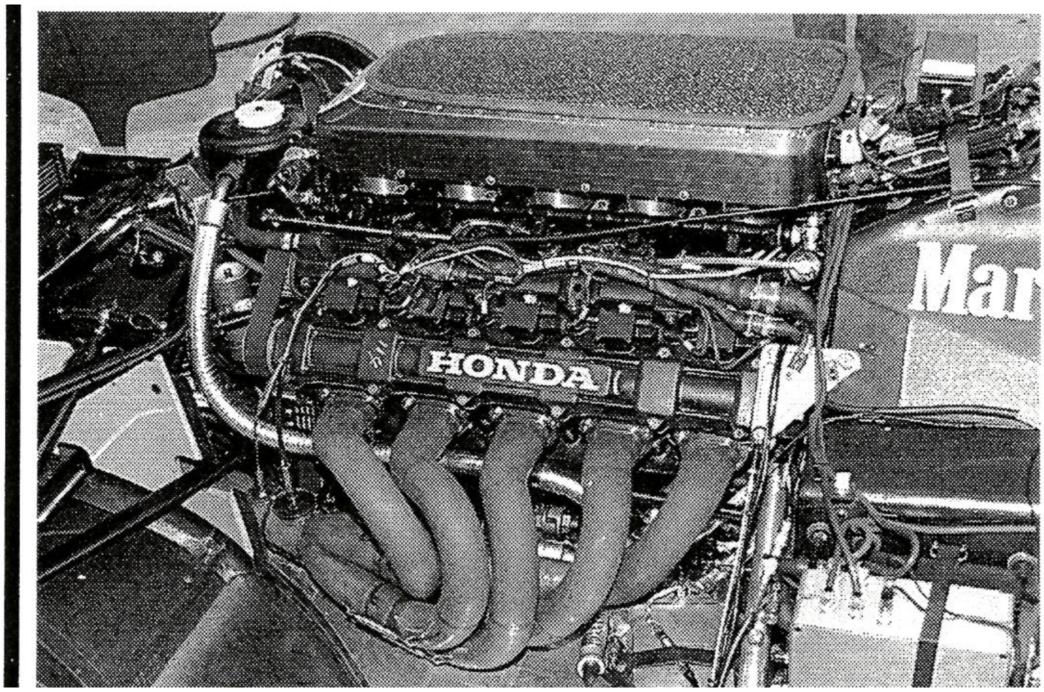
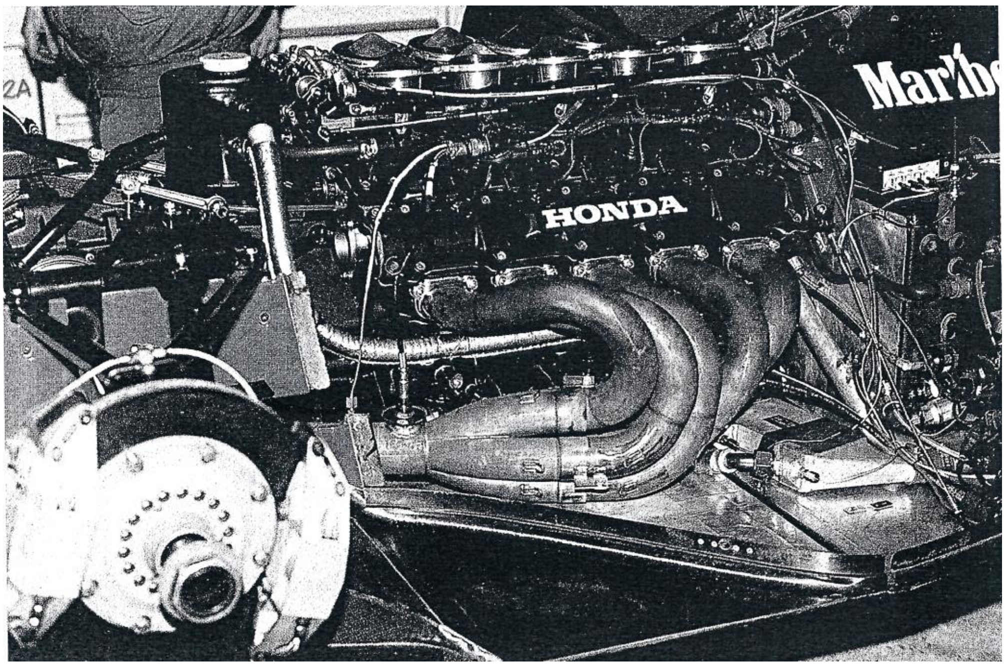


Fig. 72B
1989 Honda RA109E
72V10 89/56.2 = 1.584 3,496 cc
This shows the gear-driven camshaft version, as raced.
The intricate pipe-work to provide equal tuned lengths for each cylinder
in a limited chassis space is noteworthy.
DASO 727 p.72



<u>73. 1990 Honda RA100E; 3,493 cc; *650 HP @ 13,800 RPM*</u> (See Fig. 73A)

In the Spring of 1989 Honda decided that a V12 engine was needed to continue its run of successes (991), apparently at the insistence of Soichiro Honda himself (958). A mock-up of a 60V12 was shown in October of that year (966). While this engine was in design and development the V10 configuration was carried forward with improvements to the 1990 season. It retained the 72^0 Vee angle and the balance shaft (990).

Honda adoption of Pneumatic Valve Control System (PVRS) in 1990

Honda clearly took note from the Renault RS1 of the possibility of raising B/S ratio by using PVRS in their V10 and thereby securing higher RPM at a given MPS and so higher power. It is believed that the 1990 RA100E engine had B/S = 92/52.55 = 1.75, 10% higher than in the 1989 RA109E* and that PVRS was applied in Version 4 brought out in the season at the Hungarian GP, the 10th race.

A gain of 800 RPM over the RA109E was claimed for this version (991) which represented an increase in BNP from 19.3 m/s to 21.2 (+10%) and is consistent with the higher MVSP permitted by the new type of valve gear (Honda quoted "*a modification made in the valve return mechanism*"** (991)).

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*See Note 93 explaining this apparently anomalous pair of engine designations.

**There may have been some reluctance to admit to using a version of Renault's DP in 1990 – it *was* Patented!

Performance of the RA100E

Honda developed altogether 6 versions of the RA100E during 1990 (991). This emphasises the point made in the Introduction about more money flowing into the industry.

The *deduced* performance at the last race was:- BMPP ≈ 12.1 Bar @ MPSP = 24.2 m/s.

These specifics were about the same as the RA109E, with higher PP/V coming from the increase of 1/S from [100mm/56.2] = 1.78 to [100mm/52.55] = 1.90, +7% (see "The General Design of Racing Piston Engines" at p.3).

Internal changes, including reduced piston mass (991), avoided the extra friction which would otherwise have been incurred by the higher RPM.

After the first race Shell produced unleaded fuel for Honda in 1990. There was an unforeseen power loss from this at Imola (the 3rd race) due to valve-seat deterioration (574) which caused a reversion to leaded for the following race at Monaco only (991).

1990 results

Except for a throttle –rod breakage the RA100E suffered no failures in the season but it powered only 6 wins against a Ferrari team now led by Alain Prost (with Nigel Mansell) which also won 6 times. Both Championships *were* secured again but through a deliberate ramming by Senna of his bitter rival in the penultimate race in Japan – which he admitted a year later.

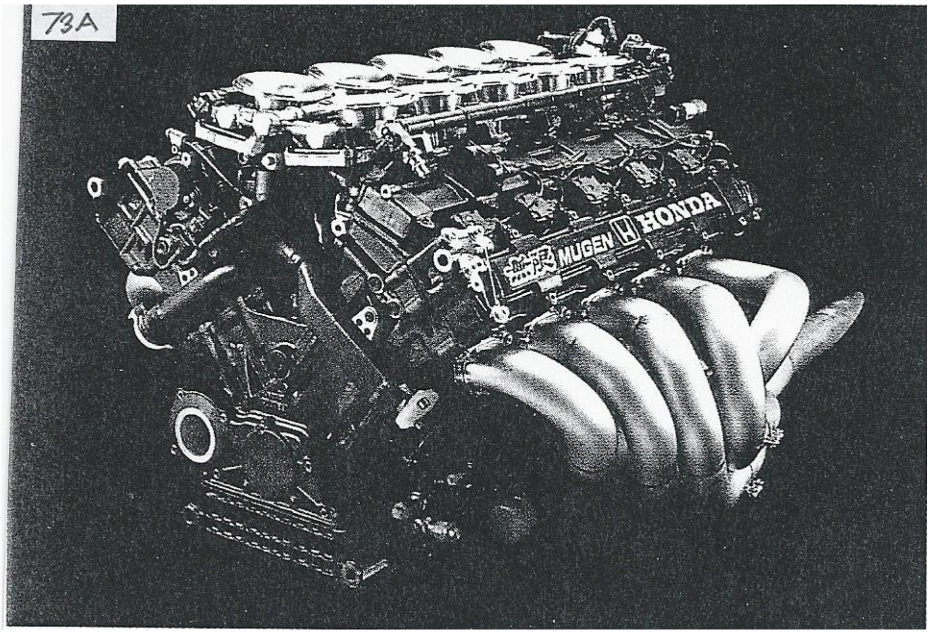
Osamu Goto

Osamu Goto was the Honda F1 Project Manager in 1990, as he had been in 1988 and 1989, his involvement with their F1 activity having begun with the revised TC engine in 1984 (991).

Post 1990

In 1991 Honda's front-line engine was the new V12, RA121E (which will be reviewed as CoY Eg. 74), but the V10 was supplied to Tyrrell as a paying customer, slightly improved as the RA101E. Their engines were to be supported by Mugen (Japanese for "*Unlimited*"), an ostensibly separate racing engine tuner founded in 1973 by Hirotoshi Honda, son of Soichiro Honda (973). No wins were secured by that combination. The Mugen-Honda cooperation was formalised in 1992 when the main company took a 40% stake in Mugen and the V10 was handed over to them for further development. This continued until the end of 2000 with various minor chassis makers, powering 1 GP win for Ligier and 3 for Jordan.

Fig.73A
1993 Mugen-Honda type MF351H
Representing Eg. 73:-
1990 Honda RA100E
72V10 92/52.55 = 1.751 3,493 cc
DASO 973



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74. 1991 Honda *RA121E/B*; 3,498 cc; *764 HP @ 13,700 RPM* (See Figs. 74A & 74B)

The 1st Honda 60V12 engine ran on the dyno in October 1989 and it was exhibited at the Tokyo Motor Show in the same month. This was about 8 months from the start of design in Spring 1989. The 1st track test, at Silverstone in a McLaren was about 9 months later in June 1990. Further running was done at Monza, Hungaroring and Estoril before the end of the year (all dates from (991)). This amount of pre-race testing was unprecedented for any racing engine.

V12 vs. V10

It is believed that the initial B/S was *83/53.8 = 1.54*, i.e. similar to the *first* Honda V10. An official comparison between the new V12 engine and the *revised* V10 was (991):-

Type	RA101E*	RA121E	
Configuration	72V10	60V12	
Length mm	620	670	+8.1%
Height mm	550	520	-5.5%
Width mm	540	530	-1.9%
Envelope Volume L	184.1	184.7	Negligible
Weight kg	150	150	

*The 1991 slightly-modified version of the 1990 RA100.

Deleting the balance shaft, not needed for a 12-cylinder engine, enabled weight to be kept the same.

Honda announced at the start of the season that the V12 produced "*much more power*" than the final 1990 V10. This may have been due to reduced friction because initially the RA121E ran at 13,000 RPM, substantially below the 13,800 RPM of the RA100E. The comparative values of [NP x $(MPSP)^2$] (see Note 99) were thought to be:-

		RA100E	RA121E	
NP x (MPSP)^2	RPM.(m/s)^2	80.6.10^5	70.7.10^5	-12.4%

Project Manager

Michio Kawamoto was the Project Manager at the Wako R & D Centre, taking over from Osamu Goto*, with Akimasa Yasuoka in charge at races (991).

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*After a spell at McLaren Osamu Goto went in 1993 to Ferrari when there was a technical interchange on V12s between the two companies.

Redesign of the V12

The McLaren MP4/6 with the RA121E won the first 4 races of 1991 while its nearest rival, the Williams FW14 with the Renault RS3 and a new change-on-wheel SAGB (following Ferrari's lead) was suffering unreliability of that box. Later Williams clearly had reversed the competitive situation while Honda had failures of bearings due to oil starvation at high 'g' (727, 743).

Honda then bravely redesigned their engine completely in a few weeks to a higher B/S ratio (535, 711), 86.5/49.6 = 1.74 (+13%), i.e. to the same ratio as the 1990 V10. This was RA121 "Version 3" or perhaps *RA121E/B*.

Meanwhile Shell had been developing better fuel, still of course to the calibration figure of 102RON. Very embarrassingly, when the new engine first appeared at the British GP some discrepancy between fuel characteristics and the McLaren flowmeter led to Senna running out of "petrol" with only ½ lap to go while lying 2nd (the no-refuelling in the race being still in force)!

This last-lap fiasco was then repeated at the following German GP!

After that 5 race no-win drought the victories began again in Hungary, the 10th race.

Honda Variable Induction System (VIS)

In the 11th race (Belgium) Honda introduced their "Variable Induction System" (VIS). This provided telescopic inlet tracts to retune the flow resonance at off-power-peak RPM so as to give a less-peaky torque curve. This idea was not actually new: Mercedes-Benz had tested "VIS" back in 1955 for their intended 1956 3L Racing-Sports car which was cancelled (see Note 100).

Performance gain after mid-season

The overall gain from the short-stroke VIS engine *plus* fuel chemistry can be shown as follows:-

Circuit	Magny-Cours	Spa
Race	7th: French 7 July 1991	11th: Belgian 25 August 1991
	Qualifying Speed comparisons	
Pole Datum	Patrese FW14/RS3	Senna MP4/6 RA121E Version 3 + VIS
	3rd Senna MP4/6 RA121E Version 2	3rd Mansell FW14/RS3
	Senna 0.4% slower	Senna 0.9% faster

McLaren/Honda/Shell therefore had obtained *at least* 0.4% + 0.9% = 1.3% of Qualifying speed relative to Williams/Renault/Elf (fuel) (who may have improved) in 7 weeks.

RPM gain

Sound recording analyses by Bernard Dudot of Renault and other reports suggested that Honda had gained in "Red-line" RPM from about 14,000 to 15,000 (574) (see Note 109 for an interesting comparison of all 1991 GP engines obtained by this method).

Final 1991 Performance

Altogether over the season Honda and Shell gained 90HP, credited equally to "Fuel + Combustion" and "Other engine development" (535).

The final performance is believed to have been:-
BMPP = 14.3 Bar @ MPSP = 22.7 m/s;
ECOM = 59%;
BNP = 19.8 m/s;
$[NP \times (MPSP)^2] = 70.3.10^5$ $RPM.(m/s)^2$, still kept down to avoid excessive friction.

<u>1991 results</u>

The dual Championships were retained with “7½” wins from “15½” races (the Australian GP was halted very early due to rain).

Fig. 74A
1991 Honda RA121 Version 1
60V12 *83/53.8 = 1.543 3,493 cc*
This is the engine as exhibited at the Tokyo Motor Show in October 1989, over 16 months before it powered the McLaren MP4/6 to victory.

DASO 966

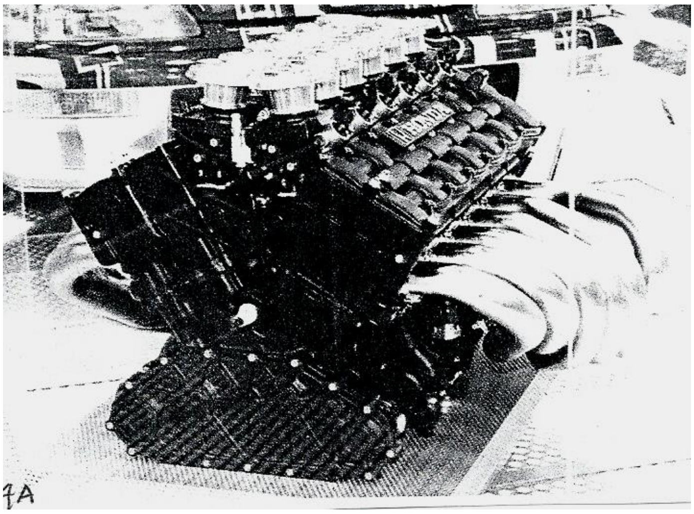
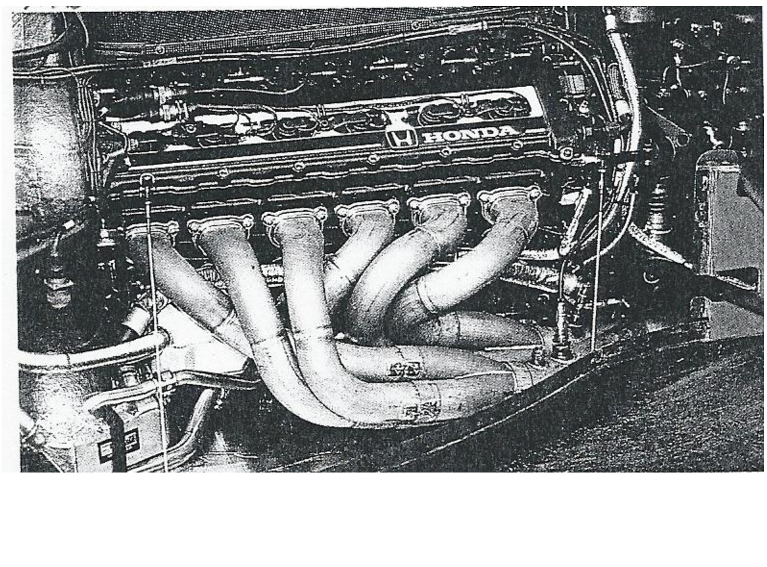


Fig. 74B
1991 Honda RA121E Version 3 or *RA121E/B*
60V12 86.5/49.6 = 1.744 3,498 cc
This is *believed* to be the redesigned engine which raced first in the British Grand Prix.

DASO 743



75. 1992 Renault RS4; 3,498 cc; 760 HP @ 14,200 RPM (See Figs. 75A & 75B)

The origin of the Renault 3.5L V10 series has already been described in the Introduction to the 3NA era. It was available exclusively to the Williams team for 1989 – 1991 and also to Ligier in 1992, during which period the results were:-

Year	Engine version	Car	Wins	Winning driver
1989	RS1 (5 "Evolutions" (574)	FW12C & FW13	2	Boutsen
1990	RS2	FW13B	2	Boutsen 1, Patrese 1
1991	RS3 & RS3B	FW14	7	Mansell 5, Patrese 2
1992	RS3C & RS4	FW14B	10	Mansell 9, Patrese 1

This steady improvement was due largely to chassis development; Adrian Newey joined Williams in mid-1990; a SAGB was introduced in 1991; in 1992 came active suspension (a reliable outcome of original 1987 – 1988 designs) and traction control (cutting – out 1 or more cylinders to prevent wheelspin (see Note 101)).

A further plus was the return of Nigel Mansell for 1991.

Special Elf fuel – costing $200/Litre in 1991 (743)! – did contribute to higher power until August 1992 when FISA enforced tighter petrol controls.

The chosen Renault V10 Vee angle was 67^0, 5^0 less than the "natural" 72^0, and no balance shaft was fitted, unlike the Honda 72V10. It must be assumed that the FW chassis were sufficiently robust to absorb the unbalanced V10 primary couple – Patrick Head of Williams was used to rough Cosworth DFV and Honda TC engines – although, perhaps, the engine weight saved had to be used to strengthen the chassis for that reason.

The RS1 had its camshafts belt-driven from the front, like all Renault racing engines since the CH1 2L of 1972. This was changed to gear drive for the RS2, which also had a lower Centre of Gravity (922), was slightly lighter (139 kg vs. 141) and was 45 mm shorter (623 mm vs. 668 (1017)).

All the Renault engines had their "*Distribution Pneumatique*" valve return system, whose advantages were described in Eg. 73, which was copied by every other engine builder from 1990 onwards.

The man in charge of Renault*sport* (hence the RS designation) at Viry-Chatillon during this NA engine design and development (continuing until the end of 1997) was Bernard Dudot. He had also played the leading part in the earlier 1.5L TC programme (also copied by everyone else). He was assisted by J-J His after the latter returned from Ferrari in 1989 (938).

Renault refused to supply significant data on any of their engines, either while active or after their retirement at the end of 1997 (994, 1017), except external dimensions and claimed weights. The quoted RS4 power, from ref. (589), is, however, believed to be official.

Renault's adherence to the V10 configuration

Despite knowing that Honda were developing a V12 engine from 1989 onwards and Cosworth another V12 from 1991, Renault did not deviate from a V10 and subsequent events proved them right. As one advantage, anticipating later Ferrari information which compared the V10 and V12 configurations, that firm claimed that their 1996 V10 required 10% less cooling surface than their V12 (938). Certainly race reports for 1992 indicated that the FW14B started with less fuel than the MP4/7A/RA122E/B (997).

1992: RS3C and RS4

The 1992 season began with the RS3C version which powered Mansell to 5 straight wins and a 2nd place at Monaco (after a pit-stop when leading caused by a loosened wheel), plus 3 more wins to the end of July.

The RS4 was introduced for Qualification only at the 4th race (Spain) and did this duty for 7 events. "Informed estimates" from the racing industry put B/S at 93/51.5 = 1.81 (47) giving an extra 400 RPM (574). It was raced first at the 11^{th} race (Hungary) in August and it partnered a further 2 Williams' wins in the rest of the season.

Up to the 10^{th} race there had been no Renault engine failures for 18 months, i.e. 26 races in all. The FISA-enforced change to "Real Petrol" in the RS4 when raced at Hungary spoiled this record.

RS4 unreliability

Ignition had to be retarded with the effective reduction of Octane value and this, coupled with the higher RPM, led to a valve failure in Hungary. It also produced unforeseen vibration which damaged several parts (919). At round 12, Spa, a mostly wet race, individual ignition coils were shaken off sparking plugs in both cars (996). Mansell was then unable to overhaul Michael Schumacher's Benetton-Ford HB7 which had gained the lead after the German changed to faster slick tyres from wets one lap before the rest of the field, as the track dried out [this began Schumacher's 91 Grand Prix wins and 7 Championships].

At Monza for the 13^{th} race both Renaults had hydraulic pump failures because engine vibration had caused a "plastic component" to break and this loss of pressure meant no gear-change and also active suspension awry (574). Another report (996) put it that the pump drive belts were shaken off – it may be that the plastic parts were pulleys! The next event saw a similar failure in one car in practice. At the following Japanese GP a pair of cracked sumps occurred, one in practice which caused a late change on Patrese's car (which never-the-less was the winner); the second led to a blow-up in the race for Mansell after conceding the lead to Patrese (997).

While a comparison of reliability before and after the compulsory use of "pump petrol" makes sorry reading, it should be realised that only 6 days notice of this change was given by FISA (10^{th} to 16^{th} August) where there had been 3 years of testing with special fuel.

Dudot's "Secret weapon"

Concerning engine development, by this date Renault had one Viry-Chatillon test-bed of their 6 fitted up to test engine, gearbox and back-axle complete, driving 2 dynamometers, to a running schedule simulating various circuits (996). Of course this could not simulate the lateral and longitudinal accelerations imposed on the car, which was still a source of surprises.

Dudot was reported as calling this rig his "Secret weapon" and saying that he learnt more from it than from anything else (1048).

RS4 Performance

Without internal data, the only performance factors which can be given are:-
BMPP = 13.7 Bar @ MPSP = 24.4 m/s; ECOM ≈ 57%; BNP = 22.0 m/s.

Fig. 75A
1991 Renault RS3
Representing Eg. 75
1992 Renault RS4
67V10 *93/51.5 = 1.806 3,498 cc*
All the RS series had similar external appearance.
DASO 743

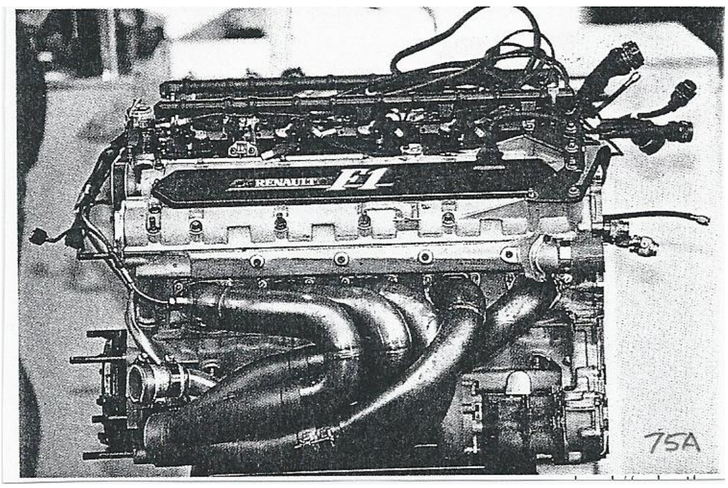
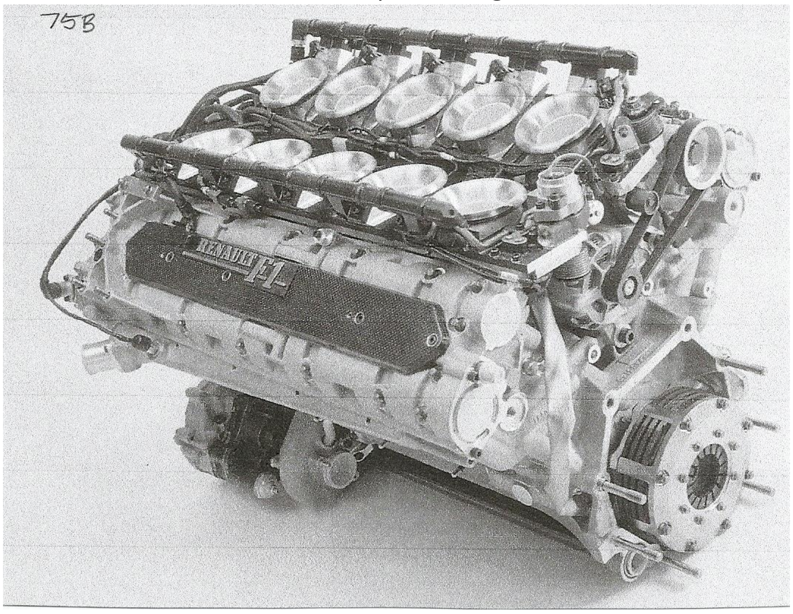


Fig. 75B
Also RS3 representing RS4



1992. Honda's retirement from Grand Prix racing

Having announced their intention publically in September 1992 Honda retired from Grand Prix racing at the end of the year.

In 9½ years from mid-1983 (5½ years 1.5L TC; 4 years 3.5L NA), powering the cars of 4 teams (Spirit only for the earliest 6 races; Williams; Lotus; and McLaren) the company had taken part in 151 classic races and had been partners in 69 victories (45.7%). With Williams they had powered 1 Constructors' title in 1986 and both Championships in 1987; with McLaren they had powered 4 double Championships, 1988 – 1991.

Their return to Grand Prix racing as purely engine suppliers to British chassis makers had therefore been vastly more successful than their first attempt in 1964 – 1968 as complete car entrants (only 2 wins from 34 races, the 2nd by courtesy of a Lola chassis redesign).

Because of the detailed data made available by Honda after their retirement the redesigned 1992 RA122E/B is described at length in "Significant Other" of this review as Eg. SO20.

76. 1993 Renault RS5; *3,498* cc; *787 HP @ 13,900 RPM* (See Fig. 76A)

The RS5, derived from the RS4, probably was in design by mid-1992 for a first test late that year. By then Renault would have known that their main rival, Honda, were not going to provide McLaren with engines in 1993. They would also probably have heard rumours that the Cosworth type VB 70V12 intended for Benetton and on test since November 1991 (82) would be dropped (which it was finally in Autumn 1992) as not being sufficiently more powerful than the latest HB (860). It also had a crank weakness (82, 605). Therefore by late 1992 a new V8 was in hand to replace the HB.

1993 outlook

Consequently a successful 1993 season was not going to be a problem for Renault, powering a Williams FW15C improved from the 1992 car by having a fully-automatic gearbox capability at driver's choice; an Anti-lock Braking System (ABS); and the new World Champion Driver (Nigel Mansell) replaced (very controversially) by a triple Champion (Prost, returning from a year out after being sacked by Ferrari in 1991).

[Concerning Mansell's departure from Williams, he then drove for Newman-Haas in the USA and won the 1993 CART Indy-car Series Championship in a Lola-Cosworth XB. He only missed an Indy 500 'rookie' win by 4.2 seconds, coming 3rd. He is the only driver to have held simultaneously the FIA and CART Championships.]

Revised injection system

A new feature on the RS5 was an overhead fuel rail feeding injectors mounted *above* the inlet trumpets(1017) (see Fig.76A). This probably enabled the telescopic inlet tract variation (VIS) to be greater.[There was an incident reported when the new engine was shown publically for the first time: a Renault engineer suddenly realised they were showing off something which they did not want the competition to see and the unit was removed hastily – it was probably this new injection layout.]

RS5 materials

Ref. (999) gave an analysis of the materials used in the 1993 RS5:-

Basic Alloy Material	%age	Parts
Al	63	Block; Heads; Pistons; Sump.
Fe	29½	Crankshaft; Camshafts; Gears.
Ti	5	Valves; Con-Rods; Bolts.
Mg	1½	Oil pump body.
Carbon Fibre Composite	1 .	Airbox; Coil shields.
	100	

Drive-By-Wire

After being humiliated in a wet 3rd race (Donington), partly because the downward gear-change system locked the rear wheels momentarily on the slippery track, the car/engine installation was improved by adopting a "Drive-By-Wire" (DBW) throttle control system at the 4th race (Imola) to ensure correct matching of engine RPM to the road speed in the chosen gear.

1993 Results

The RS5 powered 10 wins, which could perhaps have been 2 more if Prost had not secured his 4th Championship by the 14th race and then become so discouraged by outside criticism that he announced his end-year retirement, with apparently a loss of motivation.

There were only3 engine failures in the season, one of which (a broken exhaust valve) may have been because the RPM limiter did not cut in. Clearly the vibration problem of the RS4 had been solved.

Fuel consumption

Ref. (999) quotes the average fuel consumption as 63L/100 km, where the top speed (340 kph = 211 MPH) consumption – which is where full power would be employed – was 100L/100km. The Load Factor average was therefore 0.63 (neglecting different Specific Fuel Consumptions across the running range).

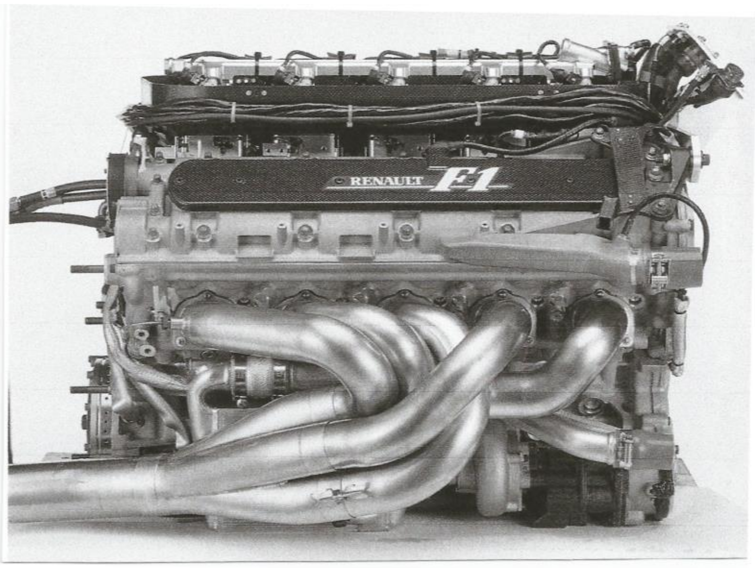


Fig.76A
1993 Renault RS5
67V10 *93/51.5 = 1.806*
3.498 cc
This shows the overhead injector rail introduced that year.

DASO 1017

77. 1994D Cosworth Zetec-R; 3,499 cc; 730 HP @13,800 RPM (See Figs. 77A & 77B)

In 1994 two major groups of changes were made by FISA under the direction of its new President, Max Mosley.

The 1st group, ordered in August 1993 for "moral" (but not safety reasons) was given effectively 8 months lead time to the start of the 1994 season (see Note 102).

The 2nd group was imposed immediately during the 1994 season for general safety reasons following the fatal accidents to Roland Ratzenberger and the triple Champion Ayrton Senna at the 3rd event (Imola) and the near-fatal crash of Karl Wendlinger at the 4th (Monaco).

The changes which affected engine design were:-

1st group:- Banning of fully-automatic gear-changing (see Note 33) and traction control. Also banned was 2-way telemetry (which could permit remote adjustment of car parameters).
Re-introduction of in-race re-fuelling.

2nd group:- Elimination of ram-air pressure-charging*.

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*Since the high over-cockpit engine intakes were not to be removed – an unacceptable loss of advertising space –vent holes totalling 1.5 x inlet area had to be cut into the downstream surfaces. At 150 MPH and ⅔ pressure recovery this would reduce power by 2%, worth ½% in lap speed.

Chassis design rule changes from the start of 1994 (from the 1993 decisions) which had some read-across to engines were:-

Banning of active suspension and also ABS
(which saved some hydraulic pump power; the former reduced the lateral 'g' obtainable and hence the problems which this caused to the lubrication system);
The 1994 decisions made various geometric changes to the chassis which reduced downforce (by about ⅓rd (920)) and this further assisted oil system design.

It could be said that the 1994 in-season changes were to appease uninformed public outcry after 12 years without a F1 driver fatality, except for a slight raising of front wing end-plates because kerb damage there probably caused Ratzenberger's later accident. The cause of Senna's crash, when cornering well within the lateral 'g' of which his car was capable (2.5 out of 4g (998 p.145) has never been determined publically even after prolonged investigation.

Division of the Championships

The Championships were split in 1994. The Drivers' was taken by Michael Schumacher in a Benetton B194-Cosworth Zetec-R after a very controversial season in which the driver was banned for 2 races and disqualified from a 2nd place, all for racing rule violations, and then disqualified from a 1st place for a technical rule breach. To cap it all, the Championship was then settled by a last-race collision with Damon Hill's Williams. The Constructors' Championship was gained by Williams with the FW16C-Renault RS6.

The Cosworth Zetec-R will be described first and the Renault is Eg.78.

Cosworth "Zetec-R" (type EC)

The new Cosworth type EC 75V8, which because of Ford's continuing financial support was afterwards designated "Zetec-R" to relate it in PR terms to that company's new Zetec DOHC narrow VIA 4v/c production engines, was begun in October 1992. This was when it became clear that the type VB 70V12 was of insufficient Power/Weight ratio. The design team was led by Nick Hayes (419). It first ran one year later and had its first track test in January 1994 in the Benetton

B194 (timescale from ref. 605). This racing team, from 1987 onward when they used the type GB 120V6 1.5L TC engine, was the chosen recipient of free engines from Ford as they endeavoured to reprise the overwhelming success of the Cosworth DFV from 1967 to 1982.

The Zetec-R drew on a quarter-of-a-Century of V8 Grand Prix engine knowledge. Details have been given previously of DFV design and development (see "The Unique Cosworth Story", including Note 84), also of the redesigned DFY in Note 88 and the 3.5L successors DFZ and DFR in Note 95; the table below summarises the data.

COSWORTH NA V8 Development 1967 – 1988

Year	1967 -1981	1982	1983	1987	1988
Type	DFV	DFV	DFY	DFZ	DFR
Principal users	See Note 84	Williams McLaren	Tyrrell	Tyrrell	Benetton
Data Source Ref.	"	18,59,61	59,62,554	47,62,207	47,62,207
Configuration	90V8	90V8	90V8	90V8	90V8
Bore/Stroke mm	85.6742/ 64.77	85.6742/ 64.77	90/ 58.8	90/ 68.6	90/ 68.6
B/S	=1.323	1.323	1.531	1.312	1.312
Swept Volume V cc	2,987	2,987	2,933	3,491	3,491
PP HP	See Note 84	515 (n1)	520	565	594
@ NP RPM	"	11,300	11,000	10,500	10,750
BMPP Bar	"	13.7	14.1	13.8	14.2
@ MPSP m/s	"	24.4	21.6	24.0	24.6
BNP m/s	"	16.1	16.5	15.8	16.1
Weight (W) kg	"	154	132	145	140
PP/W HP/kg	"	3.34	3.94	3.90	4.24
Championship wins	144	8 + 2 in 1983	1	(n2)	(n2)
Total DFV wins		154			

Notes (n)

(n1):- Judd-tuned.

(n2):- Competing against TC engines. The 1987 Tyrrell-DFZ driven by Jonathan Palmer won the Cups given that year for the best NA 3.5L car and its Driver.

The type HB series

Another table (P.17) shows what is known of the 1989 – 1993 type HB series, the design team leader for this being Geoff Goddard (419). No internal dimensions or descriptions of the latter have been published apart from 75V8, B/S = 94/63 = 1.49 (data which was a long time in being confirmed) because Cosworth, in common with most other engine makers, adopted a policy of secrecy in 1989. They did not even let Ford or Benetton know much about the engines (860). The units from then on were only overhauled at Cosworth to keep competitive eyes away. Power outputs were not published. Figures tabled are from "well-informed but not official" sources, as listed.

Given that *caveat*, the rise in PP/W from the developed DFV of 1982 to the developed HB of 1993, from 3.3 HP/kg to 5.6, = +70% was a remarkable achievement.

COSWORTH NA V8 Development 1989 – 1993

Year	Mid 1989 (French)	Start 1990	Mid 1990 (British)	1991 Most 1992	Late 1992 (Japan)	Start 1993	Late 1993 (Belgian)
Type	HB2 (n1)	HB3	HB4	HB5	HB6 (n6)	HB7	HB8
Principal Users	Benetton throughout plus McLaren where shown			McLaren (n5)			McLaren
Data Source DASO	582	47,69,256	47	582,743, 1002	70,574, 582	71	128,574, 636,867

Configuration	75V8	unchanged through HB series (82)
B mm/S mm	94/63	
B/S	1.492	
V cc	3,498	

	HB2	HB3	HB4	HB5	HB6	HB7	HB8
PP (n2) HP	625	633	663	690? (n4)	680 (n7)	700	705? (n8)
@ NP RPM	11,500	12,200	12,500	12,800	13,000	13,000	13,000?
BMPP Bar	13.9	13.3	13.6	13.8?	13.4	13.8	13.9?
@ MPSP m/s	24.2	25.6	26.3	26.9?	27.3	27.3	27.3?
BNP m/s	18.0	19.1	19.6	20.0?	20.4	20.4	20.4?
W kg	130				125	125?	125?
PP/W HP/kg	4.81				5.44	5.6?	5.6?
Championship Wins (n3)	1		2	1 in '91 1 in '92 3 in '93 (n5)			3

Total HB series wins = 11

Notes (n)

(n1): The original HB of early 1989 suffered 3 crank failures (574) in the Benetton car, which type of failure had not occurred on the test bed and could not be reproduced there (207). The cure was to lower stresses by reducing the diameter of the lightening holes through the crank pins (1113*) (long afterwards it was found that the metal properties of the HB1 crank were inferior*). This delayed the first race of an HB until the 7th race.

(n2): Officially Cosworth never quoted the powers of the HB (605). The HPs given are therefore "informed estimates".

(n3): The wins shown for each HB mark may not be allocated correctly as earlier engines may have been up-graded later.

(n4): "*Piquet stated it was unchanged from HB4 except for special fuel*" (1002).

(n5): Purchased engines in McLaren in early 1993.

(n6): 1st PVRS (Cosworth called them "Air springs"). 2 balancing shafts added?

(n7): From a very well-informed source.

(n8): Small crank bearings (867). With improved fuel and oil at 13th race (Monza) giving +0.7% ("= 5 HP") (636).

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*DASO 1113. Advice by courtesy of Martin Walters, June 2011.

Discussion of HB design and development

To achieve its improved performance the HB had been able to exploit a higher B/S ratio (1.49 vs. 1.31 of the DFR) by using all-Ti-alloy valves (419) so that in 1989 its BNP was 18.0 m/s where the late-DFV, DFY, DFZ and DFR engines with steel* valves had peaked around 16 m/s.

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*Using “steel” as shorthand, well aware that they were Cr, Ni, etc alloys of Fe!

Still using steel wire coil valve springs, the “Red line” by 1991 was 12,800 RPM, BN = 20 m/s (605, 860). When Cosworth in 1991 first tested “Air springs” (as they preferred to call PVRS (743)) in the HB they stated that this raised RPM capability from 12,800 to 13,500 (605) i.e. +5.5%. This system was raced in late 1992 as the HB6. The “Bottom end” – bearings and pistons – then became the limiting parts (605). Smaller diameter crank bearings were introduced in late 1993 (1000) to reduce friction (HB8).

The HB had 75^0 Vee angle instead of the previous “natural” 90^0, the reduced width possibly improving airflow to the rear wing. When John Barnard joined Benetton in September 1989, as usual he demanded installational changes to the engine to suit his B191 chassis design and Cosworth obliged him with new heads and block (743).

The HB had front-end chain drive to the camshafts, replacing the previous gear-drive with its ingenious “frequency-reducer”.

The Ford Motorola production Engine Control Unit (ECU), type EEC-IV, was modified to run the HB.

As noted on the table above, crank failures delayed entry into races by about 3 months while they were cured.

1989 -1992 HB results

Despite being a lighter engine and requiring a lighter average fuel load than its Honda V10 and V12 and Renault V10 competitors, refuelling still being banned, the HB V8 series did not have enough power to win up to the end of 1992, except on a few occasions when the rivals were unreliable or crashed – or the rising-star Schumacher made a smarter move on tyres than the other drivers (Spa 1992)!

1993 HB results

In 1993 the enforced acceptance of the Cosworth HB by the McLaren team for the MP4/8, after Honda’s retirement – McLaren had to *pay* for engines 2 steps behind Benetton’s – combined with the very-high-priced talent of Ayrton Senna (rumoured to be $1m per race) made a large difference to the HB’s success. McLaren insisted on an ECU from their own associated electronics company, headed by Dr Udo Zucker who had earlier pioneered the Motronic ECU at Bosch. This unit provided traction control, calibrated by Cosworth at McLaren’s expense and failure risk because Cosworth did not like a system which cut out cylinders to avoid wheelspin. The pay-offs to McLaren were wins at the part-wet 2nd race (Brazil) and at the very wet 3rd race (Donington). Benetton did not receive a Cosworth-approved HB traction control (via throttle variation (1004)) until the 6th race (Monaco) (1003)

The1993 season ended on a high note with 3 consecutive wins (in the 14th race onwards won by Schumacher in the Benetton B193B)) by HB-powered cars. McLaren’s engines by then were up to the latest specification and Senna took the last 2 races.

This late run of victories *apparently* augured well for the up-coming Zetec-R in the B194 for the next season. However, it had to be evaluated against the fact that Alain Prost had secured the Drivers’ Championship at the 14th race in the Williams FW15C-Renault RS5 and, having announced his forthcoming retirement at the end of the year, was probably not trying too hard.

Zetec-R details

To obtain greater power than the HB8, the Zetec-R had to run faster and hence needed a higher B/S ratio at 100/55.69 = 1.8 (529). A bore of 100 mm had not been seen in CoY since 1913 and has not been surpassed up to the time of writing.

The "Top-end" problem had now been solved with PVRS. The piston problem of the late HBs had still to be solved. In the first 4 months of Z-R testing it has been reported that 15 different designs were tried (565, 695). An Mg-alloy piston was tried (82), said to weigh only 305 grams ((938) believed to be inclusive of 2 rings and a short steel gudgeon pin, about 70% of Al-alloy) but this did not last. A reversion was then made to forged RR58 Al-alloy with Cosworth-improved process control (1113).

Another material innovation which did apparently succeed was a ceramic insert in the combustion chamber (82), presumably to permit larger valves without causing cracks between the seats.

Front-end cam drive by chain was retained – the only such drive in contemporary engines.

The valves were all, as in the HB, Ti-alloy and also hollow-stemmed (82). Cosworth had developed the valves in conjunction with the US pioneer of the material for racing, Del West, with heads welded to the stems to improve material utilisation. The alloy was the American "workhorse" Ti6Al4V. They were then bought from Del West at $100 each (317).

Con.-rods were now also Ti-alloy – a costly material change long resisted by Cosworth. The big-ends were *not round* as made to allow for distortion under load when running (419).

Barrel throttles, close to the inlet ports, replaced sliding-plate control of airflow because they could be nearer the valves (82) and so reduce slightly the time between opening and power pick-up (419).

VIS was not used.

The ECU was based on the Motorola EEC-V then going into production Fords. This, with port fuel injection and transistorised ignition provided great RPM flexibility – this was proved at the 5th race (Spain) when Schumacher's Benetton was 1st at ⅓rd distance and then had a gearbox malfunction which left him only 5th gear. After adapting to this situation his lap times dropped only 2% (920) and he was actually able to re-start after a pit-stop to refuel and finish 2nd! Telemetry to TV at the next race showed that the Z-R could pull away from only 4,750 RPM, 35% of the maximum shown of 13,750 (574).

Zetec-R 1994 results

With Schumacher driving the Benetton B194-Cosworth Zetec-R the 1st race (Brazil) was a victory, repeating the DFV debut 27 years earlier.

Seven more wins were taken in 1994 despite the bans and disqualifications mentioned earlier – and a single engine failure in the 9th race (Hockenheim). A more prudent team management of their driver might have secured the dual Championships without the controversial final-race collision. As it was the Williams team took the Constructors' title.

The result was remarkable for a V8 competing with a V10 in a year when refuelling had been re-introduced, which was a rule change *long after Cosworth began to design their engine.* At a stroke of FISA's pen this halved the average advantage in fuel weight carried (assuming both types refuelled at ½ distance).

Of course, the death of Ayrton Senna in the 3rd race affected the season's outcome, forcing Damon Hill to lead a Williams-Renault team struggling with the knowledge that it had occurred in one of their cars for an unknown reason and having also to cope with the official Italian investigation which ensued. He did rise fully to the challenge by the end of the season, as had his father in 1968 after the death of Jimmy Clark.

Performance factors for Z-R

Performance factors for the Z-R were:- BMPP = 13.5 Bar @ MPSP = 25.6 m/s.
ECOM, assuming R = 12, was 56%.
BNP = 23.0 m/s.

Figs. 77A & 77B are shown on P.20.

Fig. 77A
1994D Cosworth type EC (aka "Ford Zetec-R")
75V8 100/55.69 = 1.796 3,499 cc
By this date engines were fitted with filters to clean the inlet air, as shown.
DASO 82

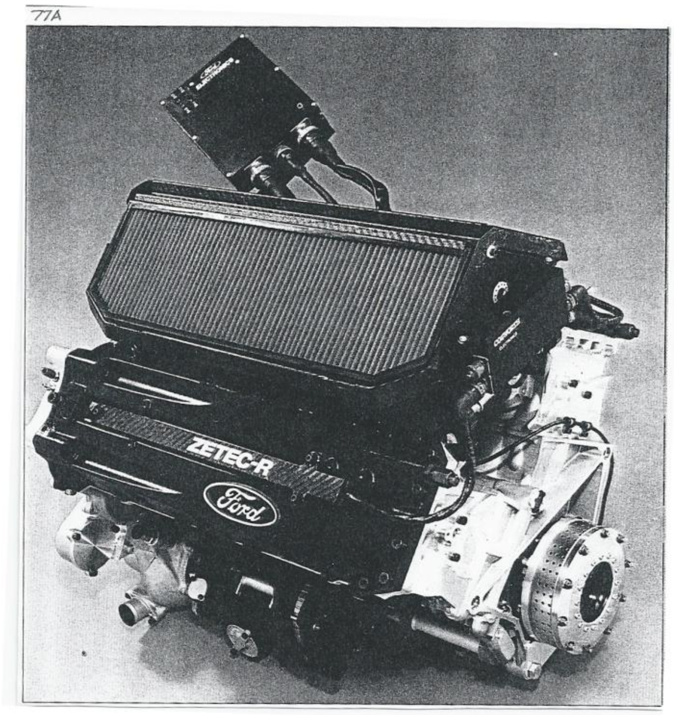
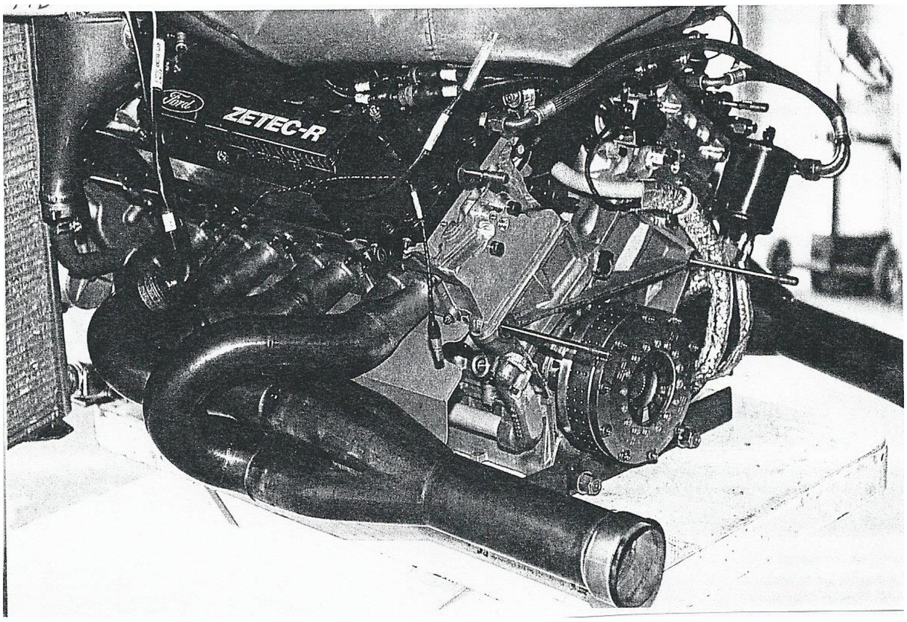


Fig. 77B
Showing the exhaust system.
DASO 958



A summary of Cosworth Grand Prix history is given on P.21.

Cosworth Grand Prix history summary

At the end of 1994 the Cosworth Grand Prix score, all with V8s, was:-

DFV	154
DFY	1
HB	11
EC (Z-R)	8
	174

The Cosworth Zetec-R of 1994 was the last hurrah of the V8 engine in Grand Prix racing until Max Mosley's FIA *dictated* its use after 2005.

The year 1994 was also effectively the end of Cosworth as a supplier of front rank Grand Prix engines.

Having achieved together a 1st Championship, after 8 years of trying, Benetton and Ford then severed their relationship.

Post-1994 Cosworth persevered optimistically with V8 adaptations to the new 3L rule but with no further success. Not until 5 years later (1999) did a Cosworth V10 engine (type CR1) power a GP winner and a further 3 years passed before this occurred again, in 1993 with the type CR4 V10.

The Cosworth GP score to the end of this review period was therefore 176 wins. It did not increase again to the time of writing. The company left the Grand Prix arena at the end of 2006, came back again with rear-rank teams in 2010 to 2012 but now may have retired for good, not being funded to participate in the 3rd PC (TC) era starting in 2014.

It was not until early 2004 that Ferrari finally surpassed the Cosworth Grand Prix total of wins, despite having been on that scene for 19 years before them.

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78. 1994C Renault RS6; 3,498 cc; 770 HP @ 14,600 RPM (See Fig. 78A)

The effect of the Benetton team's clashes with the FISA authorities was to award the 1994 Constructors' Championship to Williams, since disqualification took 17 points from the former and added 4 points to the latter who ultimately had a winning margin of 15 (*before* considering the effect on wins of the 2 race ban on Benetton's Schumacher). The Renault RS6 therefore enters this review of CoY.

The RS6 was still 67V10 and Bernard Dudot seemed to confirm 2 years later that B/S = 94/50.4 = 1.87 (974). The design originally had to take account of another of the dramatic February 1993 pronouncements of the FISA President Max Mosley that engines after 1993 would have to last a race weekend *at least*. When this restriction was *not* confirmed in August 1993, Renault re-designed for the usual 1-race life and hence more power (82). Initially the RS6 had 400 RPM more than the RS5 (1017).

At the 7th race (French) an improved version was available (RS6B), at first for Qualification and then raced at the 9th (German).

There was another Q. step at the 12th (Italian) (RS6C), raced at the 13th (Japanese).

Of course their PVRS was used, now standard in *all* front-line engines – it appears that the Boudy-Renault Patent dating from an application in 1984 (474) was simply ignored! The Renault system was re-designed for the RS6B (1017). As described in Note 103 the low-friction hard-coating "Diamond-Like Carbon" (DLC) had just been developed successfully in France for valve-gear application and it is very probable that this was applied to the RS6 and subsequent Renault racing engines.

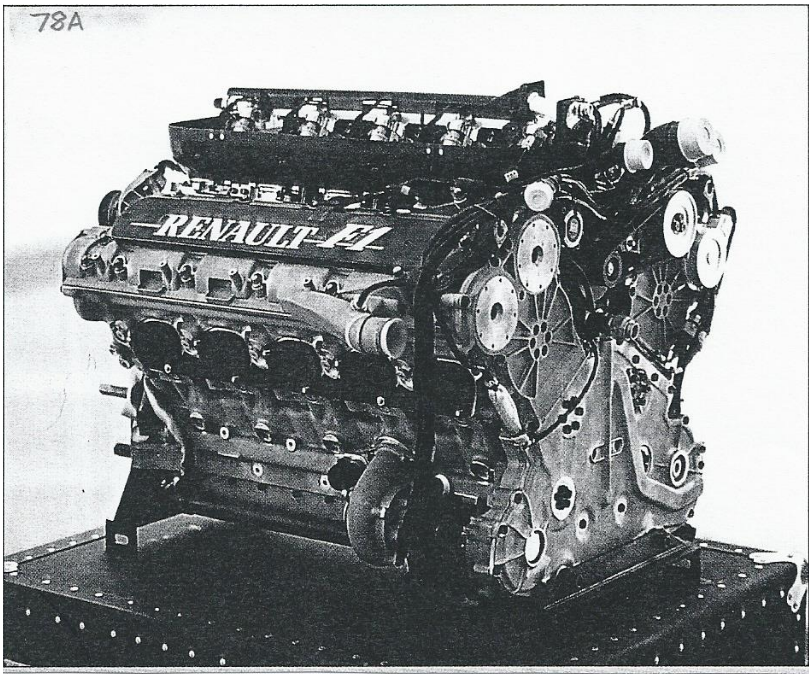
Computerised methods in engine design

The engine consultants Ricardo were permitted to advertise in early 1994 that Renault were using their computerised WAVE programme to simulate RS unit performance, this taking into account geometric changes affecting the fluctuation of air/mixture/exhaust gas flows. J-J His also confirmed in 2000 that Computational Fluid Dynamics (CFD) programmes were used at Renault*sport* throughout the '90s but that they were not then capable of deciding design features without dynamometer verification (1018). That *caveat* was probably true to the end of this review period.

RS6 Performance factors

The approximate RS6 performance factors were:-
BMPP = 13.5 Bar @ MPSP = 24.5 m/s;
ECOM, assuming R = 12, ≈ 56%;
BNP = 22.9 m/s.
There were no engine-related DNF for Williams (or Ligier) in 1994.

Fig. 78A
1994C Renault RS6
67V10 94/50.4 = 1.865 3,498 cc
Note the common overhead fuel rail feeding the above-trumpet injectors.
This feature had been introduced on the RS5 in 1993.
DASO 82



The reduction of Swept Volume for 1995

From an FIA WMSC decision of June 1994 following the Imola accidents, in the group of rapid changes already described for that year, the maximum swept volume (V) for 1995 was reduced from 3.5L to 3L.

This was actually an official ratification of a proposal by the engine manufacturers after they objected to an earlier FIA threat to reduce power by means of a fuel-flow limiter (565).

The resultant CoY engines will be described in the

3rd Naturally-Aspirated Era (3NA), Part 2, 1995 -2000 (end of this review); Egs. 79 to 85

Egs. 84 and 85 are already posted on the site.