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## Indycar 1990-99



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# Managing expectations at Indy

The age-old problem of rising speeds and stepping into the unknown is revisited

By Andrew Cotton

Motor racing continues to evolve year on year, yet some things just remain the same. We can all put on our rose-tinted spectacles and look at the days gone by, thinking that they were better. In this special edition of Racecar Engineering, we look back at our coverage of the IndyCars of the 1990s and, given the dramas in testing and qualifying for this year's Indianapolis 500, it is interesting to note the similarities between the two eras. In the 1990s there was an all-out engine war between Honda, Ford, Chevrolet, Toyota and Mercedes. The engine regulations worked and the value of the series was at its peak at the time that Racecar Engineering started its extensive coverage. Penske, Lola, Swift and Eagle were also having at it in a chassis war so there was nothing wrong in terms of competition. Today's IndyCar is a different world, with a spec chassis and for the first time in a long time, technical innovation with the competing manufacturers Chevrolet and Honda allowed to produce new aero kits (see Racecar Engineering V25N5). The introduction of the new kits has not been a smooth process, with limits put on the amount of development in order to avoid having to redesign the entire car, but in practice for the Indianapolis 500, four cars have crashed heavily.

The fact that the race is going ahead suggests that IndyCar has a grip on the situation and is prepared to push ahead with the competition, which in itself is an encouraging sign. There are reasons for the crashes, but as one engineer here put it, you cannot rule out old-fashioned co-incidence. Back in 1998, ChampCar introduced the Handford Device, a new rear wing design that was supposed to slow the cars by 20mph following record speeds the previous year. What happened was that the drivers complained that they were running too close, and questioned whether nor not single seat racing should be like that. It was a classic case of the law of unintended consequence

- introduce technology for the right reason, but then watch as cars venture into new and untested territory and find a host of new problems to solve. That is the place in which IndyCar finds itself now.

A suspension failure led to James Hinchcliffe's accident and IndyCar responded by asking teams to check their parts for lifing. Josef Newgarden crashed due to a rear tyre that lost pressure. Dramatic images of cars travelling backwards and taking off have been beamed around the internet and television networks and the uproar has been deafening. From within the IndyCar paddock, however, there is silence and no one from the technical teams are talking on the record as the world demands answers, and surely there are answers to be had. Are the aero kits to blame for these big accidents? That's certainly one that IndyCar cannot yet answer as there is no valid data or proper investigation into each individual accident. Could the accidents have been avoided? Again, who can answer that one without first conclusively establishing the common factor between the accidents? What IndyCar can do is release the details that they have. They know the speeds, the conditions, the forces running through the suspension, they know the basic details at the start, during and post accident and no doubt will be poring over the data at length ahead of the big race. What it cannot afford to do is to have large accidents on a global media platform, much less even if a driver or spectator is hurt or killed.

It seems clear that there is some element or elements that have led to the crashes, but what they are will take time to find. Is it the speed, the aero kits, the tyres, the cars, the part-lifing brought on by rising costs of competition? Racing is still about competition, and competition equals speed. Managing speed is a complicated business, and the challenges facing IndyCar are precisely the same as those facing the sport in the 1990s.

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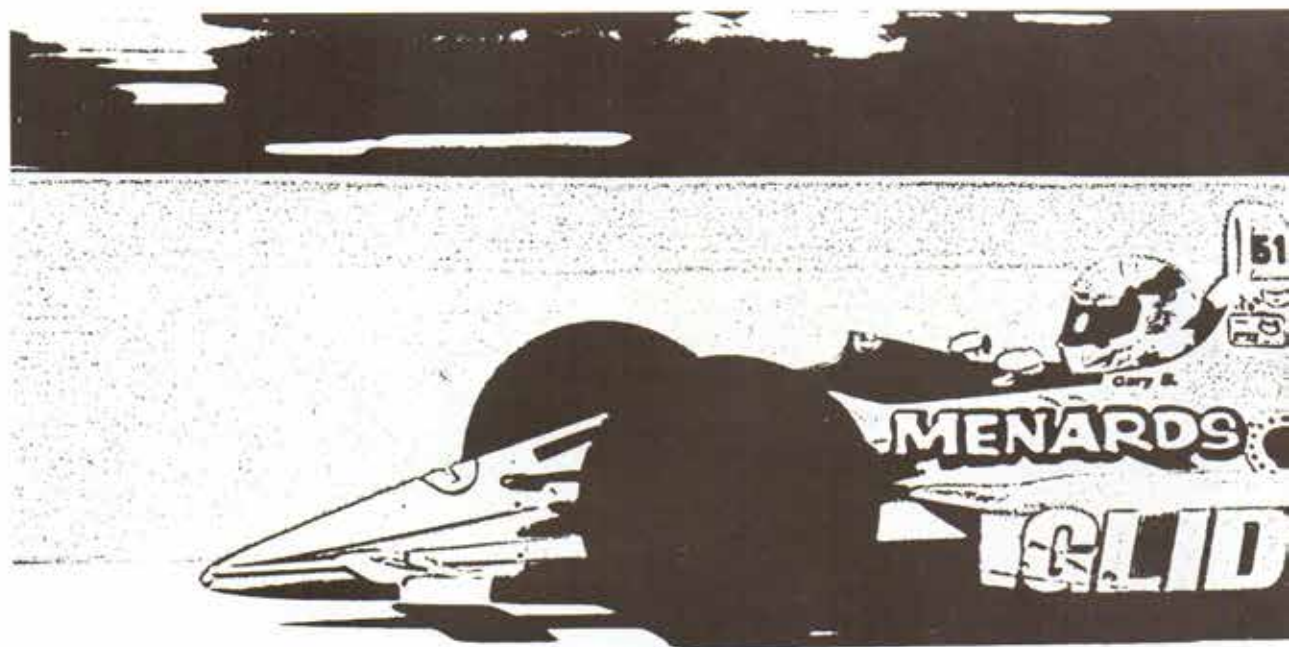
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# 224.468m.p.h.

First day of qualifying for the 1990 Indianapolis 500. Lola Cars Joint MD Mike Blanchet is talking to Larry Curry, Crew Chief of the Granatelli team which is running Kevin Cogan in a Buick-Penske. "It would be great if someone did a proper job of a Buick car", Curry comments. "We would be happy to do it if Buick would commit to it", Blanchet replies. Soon Blanchet is introduced to Jo Negri, Manager of Buick Special Projects. He asks Negri for a full commitment rather than the existing 'arm's length' involvement. That is just what he gets. The outcome is the fastest speed of 1991 qualifying - 224.468m.p.h. - and an obvious winning potential for the first ever bespoke Buick car.

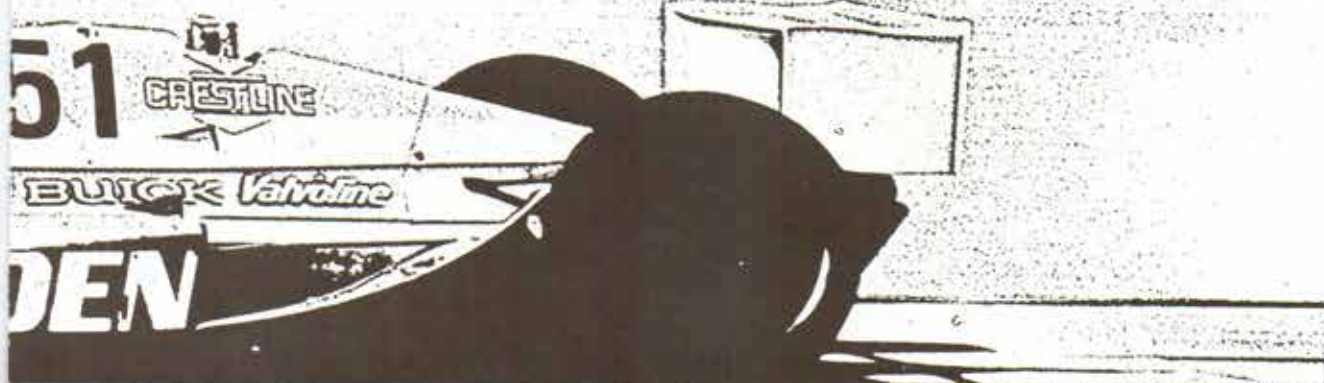
**SPECIAL  
INDY:  
BUICK  
LOLA**

Buick had been represented at the Brickyard since 1984, in which year its 90 degree V6 pushrod engine propelled a pair of Brayton-fielded March 84Cs. They took advantage from the fact that USAC permitted turbocharged stock blocks a displacement of 209cu.in. and to run 57in.Hg. mercury (approximately 1.9 bar absolute) whereas the dominant Cosworth DFX was restricted to 161cu.in. and 47in. (approximately 1.6 bar).

Scott Brayton put his example on the outside of the ninth row with a 203.637m.p.h. clocking that represented a new stock block record and was the fastest time of the second qualifying weekend, if well off the 210m.p.h. pole speed. Teammate Bedard started from the seventh row only to crash and Brayton suffered engine



Garry Bettenhausen:  
224.468 m.p.h. in  
the Menard Buick-  
Lola



failure.

In 1985 Buicks were entered by Brayton and Galles racing, each running a single March 85C. And they shocked the establishment by heading qualifying, Galles driver Carter taking pole at 212.538m.p.h. in blustery conditions which cut speed slightly and might have favoured the power characteristics of the engine. Alas, both Galles and Brayton were early retirements.

In the light of many piston failures over 2000 miles of testing were completed at the Brickyard prior to the 1986 '500' which saw three Buick cars, while a similar programme preceded the five car '87 onslaught - and still Buick didn't get a car home. And after '85 the Buick cars lived in mid grid.

The turning point was the 1988 race in which Crawford, a Buick driver since '86 who had broken both ankles after going 215m.p.h. in testing for the '87 race, managed to lead deservedly in Kenny Bernstein's '87 Lola. Crawford proved that a stock block engine could also finish, coming home sixth after a late race puncture.

In 1989 Crawford and Bernstein continued the programme and Crawford took the highest Buick four lap average speed up to 221.450m.p.h, qualifying for the second row. There he was joined by Scott Brayton in another Buick-Lola, a newer chassis run by Dick Simon. Half a dozen Buick cars started the '89 500 and that of Brayton finished, in sixth position.

1990 saw no less than one third of the field comprised of Buick cars though the highest starting was the Penske chassis of Randy Lewis on the fourth row. In 1989, partly due to the compromised handling of a car that wasn't designed specifically for the Buick engine, Crawford had suffered

another pre-race accident, this year he overcame two shunts to line up an '89 Lola chassis on the penultimate row. The highest finisher was Cogan in 11th position.

Although the Buick engine still has 10 inches mercury in its favour (these days stock blocks ran 55 inches, race engines 45 inches) the 1990 race was another dominated by the Ilmor Chevrolet engine. Blanchet could see that the Buick V6 had a lot of potential but that it needed a car to be designed around it.

"The engine was just installed in an existing V8 chassis but it was a different weight and size and also had a different power output and different characteristics". In view of that, Blanchet asked Negri to commit to a project to tailor a package around the engine and Buick responded with both financial and practical assistance.

Lola carried out a feasibility study to see what could be changed on the engine to improve its installation in a car and undertook track testing of the existing V6 in a '90 chassis to identify the key problem areas. This was followed by wind tunnel work then the design and production of a bespoke chassis for '91.

Given strictly limited sales potential, the company could not hope to recoup its investment in such a project; the Buick finance made it possible. In effect, Buick subsidised the teams that bought the Buick-Lola T91/00. On the practical level, Buick went ahead and modified the engine to suit Lola's requirements. "As a result, we were able to do a 100% job", Blanchet reflects, "and Buick was very happy with the result".

The project got underway in the autumn of 1990 when Lola engineer John Travis ran the '90 test car with Bernstein's King

Motorsports team. From September through to November Travis made three trips to Indy to oversee a total of six weeks testing during which Crawford clocked up 1200 miles. Travis was new to Indy Cars and could thus take a fresh approach to the phenomenon of the Buick engine.

As with all previous Buick cars, this one could not exploit in full the performance of the engine since the installation of the stock block unit upset the balance of the chassis. Further, with the V6 installed the car lacked adequate axle to axle torsional rigidity, even with A-frames linking the tub to the gearbox. Of course, those frames added weight while accommodation of the engine also spoiled the chassis aerodynamics.

"It drives like any other Buick car", Crawford told Travis. The Lola engineer used a sophisticated data acquisition system to pin point exactly what was wrong with the handling of the car. Indianapolis runs anti clockwise, of course, and in theory a car should compress its springs both sides, with its sprung mass rolling a little, as it takes the four slightly banked corners. The roll - a couple of degrees - takes out the static tilt with which the car is set in the pits so that the underwing runs flat through the corners.

From his acquired data, Travis found the Buick car did not compress its left hand springs but jacked up that side. It was clearly a problem of the location of the centre of gravity of the engine relative to the roll centre. The driver couldn't actually feel the chassis jacking, was merely aware of an imbalance. In the past teams had often found heavier right hand springs to be of benefit and had even resorted to ballasting, which had merely disguised the problem.



There was clearly only one solution: tackle the problem from source. This meant modifying how the engine was installed in the car and altering the wheelbase and suspension to suit. The problem was not merely one of weight transfer from left side to right but was complicated by the inevitable weight transfer from inner rear to outer front wheel that occurs when cornering.

To find the right direction for those modifications, Travis evaluated different wheelbase options, using gearbox spacers and alternative wishbones. The '90 chassis had a standard wheelbase of 113.5" and the King version was tested with longer and shorter dimensions with a final choice of 116.5" to match a new fore/aft location of the engine within the wheelbase.

Travis wanted a proper insight into the relationship between wheelbase, geometry and weight distribution and he tried eight alternative rear roll centres as well as half a dozen wheelbase options. This was a design exercise rather than fine tuning and "countless combinations" of wheelbase, roll centre and weight distribution were evaluated over the six week period.

It was clear, both from consideration of weight transfer and from the point of view of aerodynamics, that the engine should be mounted lower in the chassis. Buick's funding permitted Lola to develop a bespoke transaxle to match a lower sump version of the V6 developed by Special Products. This set the engine an undisclosed measure lower in the chassis and the engine was also modified so that it could be run fully stressed.

In the past the V6 had always been run with the A-frames and with an adapter plate between the block and a standard (V8) transaxle. "Buick had never had the advice of chassis engineers", Ashmore remarks; "we were confident that the engine could be run fully stressed".

To do this involved redesigned rocker covers to accept chassis loads and doweling the heads to the block, together with production of a higher sump facilitating the lowering of the engine in the chassis.

The new transaxle mated direct to the engine without the need for an adapter plate - which cost rigidity and added weight - and incorporated the rear suspension pick up points. With its lower and fully stressed installation, "the engine now looked as if it belonged in the car", Blanchet observes.

The revised installation saw both the clutch level and the level of the c.w.p. dropped while, as we have noted, the position of the engine within the chassis was also changed. Four bolts attached the

engine to the tub - one for each rocker cover, one each side of the sump - while the new bellhousing picked up on the usual rear mounting points and the back of the rocker covers.

Buick modified the engine as far as possible to keep it tightly packaged, thereby making the most of its compact dimensions compared to those of a V8 engine. Aside from relocation of the pumps, in particular the plenum chamber was revised. From the point of view of aerodynamics, both the smaller, lower set engine and the longer wheelbase were advantageous and Lola was able to alter the pods, underwing and tail to fully exploit the potential gain.

A suitably modified 33.3% model was run in the Cranfield rolling road facility regularly used by Lola, the tests lasting for a week. Bruce Ashmore, in overall charge of the Indy Car programme, was able to achieve important gains in terms of lift and drag figures.

Following the track and wind tunnel tests, Travis and Ashmore were able to finalise the design of a bespoke Buick car. This was derived from the T91/00 V8 chassis (illustrated in cutaway form on the back cover of the last issue).

The monocoque remained the same, aside from the engine mounting area, while the suspension followed the same basic pattern with detail design to suit the Buick car. The uprights were standard but both front and rear geometry was different. At the front the wishbones were changed, at the rear the whole package was altered thanks to the revised mountings on the bespoke transaxle.

The dampers were standard Koni items but were valved to Buick requirements while steel springs and roll bars were chosen specifically to suit the new package. Wheels, brakes and clutch were standard as were the internals of the six speed gearbox which fed through the existing spool and driveshafts.

From the carbon-carbon 5 1/2 inch clutch, the input shaft ran under the c.w.p. to the lower shaft of the gearbox carrying the layshaft gears, then up to the upper shaft carrying the change gears and then up through an intermediate gear, mounted on the pinion shaft. This system kept the c.w.p. at wheel centre height to avoid running the driveshafts at an angle.

The new transaxle housing consisted of bellhousing and gearbox case both in magnesium with one detachable gearbox side plate to access the c.w.p. The oil system for the V6 was designed by Brayton Engineering - in charge of engine preparation - and the oil tank was the same capacity as that for the Ilmor Chevrolet and

likewise lived inside the fuel tank area.

The cooling system did not need to be altered. The Buick engine passed a lot more oil but the standard (single) heat exchanger could cope with this. However, an Ilmor car could be set up to run less cooling drag since its twin radiators had less demand put upon them by their heat exchanger. An adjustable radiator exit duct panel left the V8 car with a smaller outlet in the top of the pod for less drag.

The pod form was altered only to suit the improved tail profile offered by a revised engine cover and revised 'hatches' over the suspension and gearbox. Otherwise the body was the same as the V8 car and the same front wings were fitted. However, although the V8 rear wing was retained, there had to be a different position for the wing relative to the rear wheels to maintain the maximum permitted overall length. This called for a new wing mounting.

The smaller engine cowl helped reduce drag but the most significant difference in aerodynamic terms was the revised underwing and its relationship to the relocated rear wing. The Buick underwing started the same distance behind the front wheels and to conform to the regulations had to extend no further than the rear wheel axis.

The regulations limited the maximum width and height of the tunnels, however it was important to profile the new underwing to match the new wing position and to put the centre of pressure in the right place to match the weight distribution of the car. The new underwing wouldn't have suited a V8 car in this important respect.

Former Buick cars had been a struggle to get down to the minimum weight but, in spite of its longer wheelbase, this one rolled out underweight at 1550lbs. thanks to 30lbs. saved on the engine plus the deletion of A-frames and adapter plate.

The prototype Buick car went to the King team and didn't turn a wheel until it arrived at the Speedway in late March. Crawford went straight out and ran 220m.p.h. following the set up sheet calculated in the light of the '90 track tests and the wind tunnel work. Indianapolis is a pure, undiluted engineering challenge and Travis and Ashmore had got their sums right.

Other Buick customer teams were on hand to familiarise themselves with the car and their drivers backed up the impressive 220m.p.h. laps. While King was the factory development team, a total of six new Lolas were produced for the '91 race to identical specification, two to be used by Crawford, the others for the Menard Motorsports, Hemelgarn-Byrd and Paragon Motorsports teams.

Jim Crawford:  
Buick factory  
driver with King  
Motorsports

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The new cars were sent out as rolling chassis, the customer buying an engine from Buick for whom Brayton carried out preparation. Thanks to Buick's support, the chassis was sold by Lola for the same price as the V8 version of the T91/00, even though it had been perhaps 30% altered for a relatively short production run. Further, the engine was inexpensive compared to the cost of a V8, particularly in terms of rebuilds.

Of course, the all conquering Ilmor V8 was only available to chosen teams. Would the Buick give other teams a realistic chance of Indy success?

The deal with King was that Travis would engineer Crawford and that any improvements would be passed onto the other customers. In the event, there proved no need for more than fine tuning.

Unlike previous Buick cars, the T91/00 inspired enormous confidence; the driver could run anywhere - high or low. In practice Cogan ran 226m.p.h. without extending the car and it was obvious that 230m.p.h. was well within reach.

Alas, all the qualifying days were poor running days. Pole day was upset by rain. Pole went to Rick Mears' works Chevrolet-Penske at 224.113m.p.h. while Crawford made the quickest Buick clocking at an unrepresentative 218.947m.p.h. for eighth on the grid. The following day Gary Bettenhausen's Menard car ran the fastest overall at 224.468m.p.h, still well short of Buick-Lola potential thanks to the weather.

The V6-T91/00 was cornering a lot faster than older Buick cars, enjoying higher grip and putting the engine performance to better use. Further, with its superior torsional rigidity its corner weights could be set up on the scales for repeatable rather than often misleading results.

Compared to the Ilmor cars, it enjoyed enhanced aerodynamics and more horsepower. However, a major problem was that the engine was more 'peaky', more difficult to keep close to its maximum output. With the bespoke chassis it was being extended as never before and in consequence the mapping did not suit. With new mapping for '92 more of its horsepower advantage is likely to be evident. That advantage should overcome the fact that its lower revs mean that it is higher geared and thus tends to be less responsive in traffic.

For qualifying the engine was run to 9,200r.p.m. for a full 800b.h.p. with the race run at 8,800/8,900r.p.m. for a loss of perhaps 50b.h.p. Race day performance was spoiled by reliability problems. "We designed a car that suited the engine and the engine could be used a lot harder and more problems came in", Blanchet reflects; "there is some work to do in terms of engine reliability and further optimisation of the engine/chassis package. Buick could win in '92".

Blanchet concludes: "with this car teams could be instantly competitive at a sensible price. We expect this to be even more the case with the 1992 car".

**The engine regulations at Indianapolis give the stock block Buick V6 a fair chance of success, in spite of the handicap of pushrod valve actuation. Its production base makes it a far from ideal 500 mile racing engine but Buick remains determined that its ultimate super-tuned V6 engine will find success in America's greatest race. Here we delve inside the ambitious unit.**

*Indy V6  
90 degree V6  
4.00in. x 2.76in./ 209cu.in.  
1 Garrett turbocharger  
Iron block  
Aluminium heads  
Linerless  
4 main bearings  
Plain bearings  
Steel crankshaft, 3 split pins  
Steel con rods  
Wiseco aluminium pistons  
Undisclosed rings  
Pushrod, gear driven camshaft  
2 valves/ cylinder  
1 plug/ cylinder  
Parallel valves  
2.08in. intake valve, 1.60in. exhaust  
Buick ignition  
Buick injection  
Compression ratio 10.5:1  
Maximum r.p.m. 9200*

Buick's V6 pushrod engine, produced in various displacements from 3.0 to 4.5 litres, was conceived by chopping two cylinders off a V8, hence it has a 90 degree vee angle. The different displacement versions are all produced on common tooling having fully interchangeable parts. Road going versions displace 3.0, 3.3, 3.8 and 4.1 litres with racing versions ranging from 3.0 to 4.5 litres, covering a wide variety of applications.

A 90 degree V6 with a straightforward three pin shaft (the pins disposed at 120 degree intervals) is burdened with an uneven firing order and will have an unbalanced secondary rocking couple - inherently smooth three-pin V6 engines are those with 60 or 120 degree vee angles. In 1977 Buick introduced an even fire crankshaft, having 30 degree split crankpins (in other words, there were two staggered con rod journals between each main bearing).

The base engine is a conventional pushrod V6 with two valves side by side servicing a classic wedge shape combustion chamber. It has a linerless cast iron block, cast iron heads, cast iron crank, cast iron con rods and cast aluminium pistons.

The turbocharged V6 Indy engine was developed by Buick Special Products, initially working with McLaren Engines, these days with Jim Wright and Brayton Engineering. It is based on special 'heavy duty' racing parts produced by Special Products. For the bespoke '91 Lola chassis there were important packaging modifications, making the unit 25lbs. lighter and also smaller to benefit the aerodynamic package.

The linerless race block is a high strength "Stage II" casting. Like the production item it is skirted, the crankcase walls extending roughly 60mm. below crank axis while it has solid bulkheads at the centre main bearings to accommodate full width four bolt caps. Further strength is added by an integral lifter valley and by additional ribbing throughout. The casting is produced in chrome-moly-alloyed cast iron claimed to offer 20% more strength than production iron.

The Stage II block features modified oil galleries and is used in conjunction with a cast magnesium dry sump pan. The crank is retained by steel main bearing caps. Vandervell supply the plain bearings which run on 63.47mm. journals. The split-pin style big end journals have a diameter of 57mm. The even fire racing shaft is a steel forging by Buick and has six extended balancing webs. Run without a harmonic damper, it carries an aluminium flywheel which is retained by six bolts.

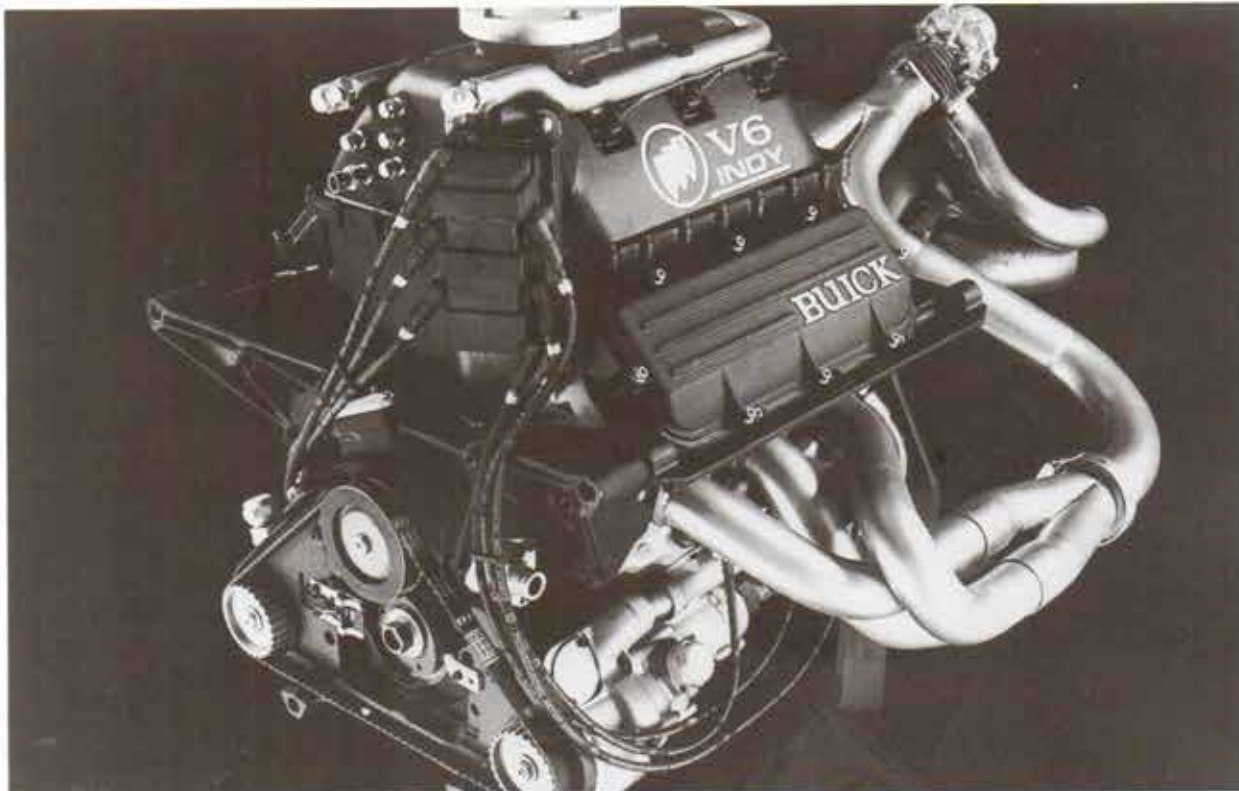
Typical H-section billet steel rods are supplied by Carrillo Industries and have a two bolt secured big end which runs on a plain Vandervell bearing. Wiseco supplies both the three ring piston and the circlip retained gudgeon pin. The top ring is Moly coated and the piston is forged aluminium. The basic design of the 'Stage II' head provides for a small combustion chamber with extensive squish area both sides of the valves, to be run in conjunction with a

**BUICK**

**Buick  
Indy V6  
V6 turbo**

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(clearance notched) flat crown piston.

Buick has made both iron and aluminium 'Stage II' heads available to the same basic pattern, a clean sheet of paper design for maximum performance. The valve sizes (2.08 and 1.60in.) are not the ultimate that could be crammed in but are seen as optimum from the point of view of gas flow, offering high velocity with the right sort of turbulence.

The aluminium head used for the current race engine is fitted with valve seats and is attached by six bolts per cylinder. Head to block sealing is via spring-filled O-rings for each cylinder with rubber O-rings for water passages. The valves are titanium on the intake side and Inconel for the exhaust. They are fitted with triple chrome silicon wire springs and titanium retainers.

Valve operation is through roller-equipped machined rockers, shaft-mounted on needle bearings. The tubular pushrods, 8.875in. long, are equipped with roller lifters. The camshaft is hardened 8620 billet steel, ground to requirements. It runs in four bearings and is gear driven off the front end through an idler. EMCO supplies the gears for the camshaft drive, which is more precise than the stock chain drive.

The drive runs in its own housing ahead of which is a special front cover which isolates the ancillary drive, taken off the camshaft drive gear, and acts as a water manifold and pump mount. This aluminium housing sets the pumps either side of the engine, the ancillary drive taking the form of a belt which wraps around a pulley each side of the crankcase. Cosworth supplies the pumps (mounted in classic 'Cosworth fashion'): on the left an oil pressure pump (plus filter) and water pump, on the right two scavenge pumps, one for the crankcase, one for the turbocharger.

The dry sump contains a crank scraper which supplies oil to a central scavenge pick up. In excess of 100p.s.i. oil pressure is run given the demands of turbocharging,

The turbocharger is a single unit as demanded by the regulations and exhaust primaries are stainless steel.

Pressure in the plenum is sensed by Buick's advanced microprocessor controlled distributorless ignition system which adjusts the timing accordingly. The Buick 'Power Source Computer Controlled Stand Alone' ignition system provides three inductive coils, each serving a pair of cylinders (thus each plug sparks twice per cycle).

The drive signals are delivered by an electronic module which contains the microprocessor and five rotary switches to programme timing advance. This module receives information from a crankshaft position sensor and a manifold absolute pressure sensor. Its programming switches set r.p.m. breakpoints and the maximum advance available to those breakpoints, plus correction according to manifold pressure.

One pair of switches control low r.p.m. ignition while after a given breakpoint another pair take over, its breakpoint a pre-set r.p.m. limit. After that limit the system starts cutting ignition to pairs of cylinders (a different pair each revolution to avoid any pair fouling). The fifth switch adds a maximum advance available as correction to the basic r.p.m. curve set by the other four in the light of manifold pressure. The Buick ignition system fires 12mm. plugs in the order 1-6-5-4-3-2.

In the early days fuel injection was not electronically controlled, being taken care of by the Bosch-Kugelfischer high pressure mechanical system which offered superb atomisation. The familiar plunger-type injection pump supplied one injector per inlet stack. However, after the '88 Indy 500 the Bernstein team started testing Buick's own electronic injection system and this is now standard.

Perhaps the greatest challenge in the development of the turbo V6 had been the production of an adequately rigid crank,

the split pin arrangement calling for some very clever metallurgy.

Two combinations of bore and stroke were originally tested, 4.00 x 2.75in. (101.6 x 69.8mm) and 3.80 x 3.06in. (96.52 x 77.7mm.) and as power and torque were virtually identical the latter combination (with an 8,600r.p.m. potential) had been adopted for a smaller piston crown. Similarly both 6.5in. (165mm.) and 5.9in. (150mm.) rods had been evaluated, again with no measurable effect on performance so the longer rod was used for less cylinder wall loading. At this stage the cylinder block height was the same as the 4.1 litre production engine at 9.535in.

The Eighties Indy Car engine was reckoned to produce around 800b.h.p. at 8,200r.p.m. on a regulation 57in. mercury compared to around 720b.h.p. for the rival Cosworth DFX on 47in, while the torque advantage was in the region of 150 lb.ft. The engine ran up to 8,600r.p.m. whereas the DFX ran to over 11,000r.p.m.

The need for a smaller package saw a reduction in block height for 1988, down to 8.280in, matching that of the 3.3 litre production engine. At the same time the bore and stroke dimensions were revised to 3.90 x 3.07in. For 1991 a 4.0in. bore was adopted as maximum engine speed increased to 9,000r.p.m: a high figure for a pushrod engine. The 4.00in. bore was used in conjunction with a con rod length of 5.50in. This year, running only 55 inches mercury, peak power was still quoted as 800b.h.p.

The compression ratio had risen from 9.25:1 to 10.5:1 and the '91 engine featured a new 'square port' version of the aluminium head. It also sported a top mounted fuel rail and injectors while specific packaging for the '91 Lola included two-piece valve covers, a revised front cover and sump and a revised intake manifold assembly.





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The Racecar Engineering App





**MARLBORO PENSKE-CHEVROLET  
1991 INDIANAPOLIS 500 WINNER**





## PENSKE PC20 CHEVROLET

By IAN BAMSEY

The Penske PC20 will always be best known for its victory in the 1991 Indianapolis 500. It brought an eighth such success for team owner Roger Penske, and the fourth for the Penske marque. Tony Matthews's revealing cutaway presents the car in its triumphant trim. This British-built conqueror of the Brickyard was based on an advanced composite monocoque produced at Penske Cars in Poole, Dorset, in which the Ilmor V8 engine, made in Brixworth, Northamptonshire, was fully stressed. A Penske Cars transaxle completed the package.

The cutaway shows the magnesium transaxle case carrying the rear suspension, with the spring/damper units horizontally mounted on top of the gearbox. The monocoque carried the front suspension, the spring/damper units being mounted upright within. The carbonfibre-over-aluminium honeycomb production was headed by a composite bulkhead, to which was bolted a composite nosebox that carried the front wings.

Behind the front bulkhead were a magnesium pedal bulkhead and a couple of aluminium diaphragms which sandwiched the spring/damper units, and helped to carry the front suspension. This layout meant that the master cylinders on the pedal bulkhead were protected by the integral front bulkhead.

Further back, there was a proper dash bulkhead, then a seat back bulkhead and a bolt-in rear bulkhead. The rear bulkhead had to be removed to access the regulation fuel tank, which was rigid and very heavy. The 33.3 gallon tank (40 US gallons) contained the fuel pump, which was cable-driven off the camshaft. A 12-pint oil tank was attached to the rear bulkhead and the tank wrapped around it.

The pushrod suspension arms were fabricated from 4130 steel tubing, aero-section for all wishbones and the front pushrods. The front rockers were aluminium, the rear steel fabrications, in each instance operating springs over Penske's own four-way adjustable gas dampers. The uprights were likewise fabricated from 4130 and contained hubs forged in 300M steel (the bearing system is undisclosed). Six steel pegs drove one-piece cast magnesium Penske rims, 10x15 front, 14x15 rear.

Titanium adjustable rollbars were fitted front and rear. The steering was

Penske rack-and-pinion in a magnesium housing. Pinions ranged from six-tooth at Indianapolis, to nine-tooth for tight street circuits.

Aluminium bells drove Alcon cast-iron discs for CART competition, Hitco carbon-carbon at the Brickyard. The Hitco discs were solid and undrilled – the driver only needed the brakes for stopping at the pits! The calipers were Alcon four-pot items, developed specifically for Penske to suit the Carbon Metallic pads run in CART races. They were one-piece machined aluminium with titanium pistons.

The transmission was described in our *Penske Race Shop* feature (in Vol 2 No 1). The inboard transverse layout of the six-speed Penske gearbox was considered "a big aerodynamic advantage" by car designer Nigel Bennett. At Indy, it drove 300M driveshafts through a steel spool, and its oil cooler was hung on the back of a water radiator (whereas it was mounted under the rear wing elsewhere).

There were alternative radiator intake ducts for the Speedway and alternative wings. The pods, tail cover and underwing were standard. The underwing was headed by small vortex generators hung on the rear of the lower front wishbone arms.

All the body panels were carbonfibre and Kevlar. The water radiators and an oil/water heat exchanger were from Secan. The pods carried the sparkbox on the left, and the AC Delco battery and the ECU on the right. The engine electronics were by GM, while the instrumentation was by GM and Pi. There were both telemetry and radio links between car and pits.

Through the season, the wheelbase of the PC20 varied between 112ins and 115ins via alternative front wishbones, according to weight distribution requirements. The longest span was used at Indy. At the Brickyard, both radiator intake and radiator exit were downsized, while the front and rear wings were all single-element without any flap. There was also a longer screen: the screen shape and the form of the head-rest area are vital, since the driver's helmet is prone to lift at 220mph!

In general, an Indycar is not as pitch-sensitive as a Formula 1 car (due to its less constrained underwing form) and consequently it runs softer springs. At Indy, PC20 wheel rates were in the region of 2000lbs front, 1750lbs rear. Wheel movement was less than seen on road circuits, where it could be as much

as 1.25-inch front, 3.0-inch rear. The PC20 suspension geometry offered anti-dive, but not anti-squat. Sometimes droop was restricted at the front, sometimes the rear roll bar was left off – not at Indy.

The downforce felt at Indy in qualifying is quoted as 3010lbs at 220mph, with 1075lbs drag. Ride height is crucial. Not necessarily as low as the PC20 could go, it was primarily determined in the wind tunnel. The car was trimmed through the angle of attack of the front and rear wings. The angle was adjusted through 8deg at the front, 5deg at the rear, and there was a range of optional Gurney tabs, up to 1-inch high.

For Indy qualifying, a car needs to be set up to run the track flat out. Even a fractional lift affects its speed over the subsequent three-quarters of a mile. But the trick is not to run so much downforce that the car is comfortable to drive flat out: that will cost too much drag. The method is to back off the downforce until it is just – just – possible to drive the lap without so much as a confidence lift. Clearly, to lap at over 225mph on tiptoe, the driver needs total commitment to each corner... Rick Mears's PC20 started the 1991 race on the pole.

On Indy 500 race day, a little more downforce is required: the driver cannot be expected to run 500 miles at tenths. Also, there is a lot of air turbulence. Consider that a draft can be picked up from a car half a mile ahead! The air swirls around the track, reducing downforce compared with that produced in the still air of qualifying. Clearly, running flat still requires concentration and commitment.

The prototype PC20 first ran at Indy in March 1991, over two days during which good lap times were recorded, but without the anticipated straightline speed. For various reasons, wind tunnel comparison with the drag of the 1990 car had been misleading. Bennett went back to the Southampton University wind tunnel for a nine-day drag reduction programme. "We had to rethink details of the top body and the rear wing design," he confirmed.

Five cars were produced for the race, and they were very quick throughout the month of May, showing an aerodynamic superiority over the Lola-based opposition. Bennett reckons that aerodynamics is 85% of chassis performance at Indy. Towards the end of the 500, Mears found a "perfect" balance, and that, in the end, was his winning edge. ■

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## GALMER'S 1992 INDIANAPOLIS 500 VICTORY

Question: What do Alan Mertens, Colin Chapman, Bruce McLaren, differential maker Vernon Gleasman, and helmet king Bill Simpson have in common? Answer: All have been recipients of the prestigious Louis Schwitzer Award of the Society of Automotive Engineers. Mertens received the 1992 award for his design of the new Galmer IndyCar, immediately prior to the Indianapolis 500 – which a Galmer, driven by Al Unser Jr, promptly won! So Galmer Engineering certainly spent the month of May 1992

# STRIKING GOLD



To the victor, the spoils: Al Unser Jr – in action at right – continues the family tradition at the Indianapolis Motor Speedway.

By IAN BAMSEY

**T**he Indianapolis winning Galmer G92 is the evolution of the G91, the unraced prototype which was the first chassis project of Galmer Engineering. A small, young company, Galmer Engineering is owned jointly by the team owner, Rick Galles, and engineer Alan Mertens.

Based in the old March factory in Murdock Road, it is a tightly knit operation, managed by Shay Campbell. Bernie Markus was the aerodynamicist responsible for the shape of the Galmer G91, but he left at the end of last year, to be replaced by Andy Brown, formerly with Leyton House and Brabham.

In addition to the MIRA facility used by Markus (see panel), Brown has used the Leyton House rolling-road wind tunnel, concentrating mainly on front wing development. At Leyton House, he also found a small but significant improvement in the underwing. In fact, the Galmer G92 came to Indianapolis as a racecar already proven to possess the outstanding aerodynamics which had been central to its design philosophy, as recognised by the SAE award.

The front wing had been the only serious problem with the Galmer G91 test-mule, which was first run at Big Springs in August 1991. Before finalising the design of the G92, the prototype was run twice at Big Springs and once at Phoenix, clocking up around 100 miles per day over six days. Through the winter, testing continued at Laguna Seca, at Phoenix and then at Indianapolis for two washed-out days. The G91 had one final test at Big Springs early this year prior to the arrival of the G92.

Compared with the prototype, the main characteristic of the G92 was a lower cockpit fairing and roll-hoop.

The G92 had a one-day shakedown at Big Springs prior to its race debut in the 1992 CART PPG IndyCar series opener at Surfers Paradise. Al Unser Jr claimed pole position: he and team mate Danny Sullivan led until it rained. That the cars slipped back in the wet underlined the fact that the front wing package was still evolving. The definitive wing arrived at Phoenix.

Through the winter tests, the team had been able to find a way to compensate for the deficiencies of the original wing. However, a mechanical fix for an aerodynamic problem was far from ideal. In effect, the rear of the car had been stiffened up to compensate for ►



## GALMER'S LOUIS SCHWITZER AWARD

IN UNDERLINING THE SIGNIFICANCE of its Louis Schwitzer accolade, the SAE commented, "With an international membership exceeding 56,000, we are in a unique position to recognise engineering excellence and innovation in racecar design and development."

Making its choice on the occasion of each Indianapolis 500 race, the Schwitzer Awards Committee takes into account the dazzling array of technology on display in Gasoline Alley. This year, the pre-race awards banquet was widely expected to be held in honour of the creators of the Cosworth Ford XB engine. But the committee was more impressed by Alan Merten's Galmer G92 chassis: in particular, "Its unique aerodynamic shape which emphasises packaging the car in the smallest envelope while improving structural integrity."

The philosophy behind the Galmer, indeed, had been to package the chassis as tightly as possible around its conventional V8 engine, while a reduction of fuselage cross-sectional area compared with a Lola improves the feed to the rear wing and the drag coefficient. It was, indeed, the success of this philosophy that led to its creator being honoured by the SAE.

Built on a 111-inch wheelbase (which is extended to 113-inch for speedway use via alternative front suspension linkages), the Galmer is a notably compact chassis. It is based on a high-sided, advanced composite monocoque with a small cockpit opening. The monocoque has a 3/4-inch honeycomb core running its entire length, and is constructed without the usual midriff split-line, its layup being done through an access panel in the floor.

The Galmer monocoque is said to be very rigid, and exceptionally strong and safe. It is felt that the usual horizontal split-line adversely affects crash performance, since its reinforcement belt tends to splinter, pulling away chunks of material that should instead crumble so as to dissipate energy.

Very careful consideration was given to the crash-worthiness of the Galmer. For example, the pedals are mounted on a sliding aluminium bracket, rather than the composite front bulkhead: in the event of frontal impact, the entire pedal assembly can therefore slide back, with the pedals perpendicular to the floor. This minimises the danger of Achilles tendon damage to the driver.

The monocoque dispenses with a central fuselage fairing and the engine cover is very low and narrow by conventional Chevrolet engine standards. The Galmer is also notable for top exit pods and a twin-orifice turbocharger inlet. The exhaust of the mandatory single turbo is likewise split, one wastegate pipe and one main pipe emerging above each diffuser tunnel exit to help to energise the underwing airflow.

Also worthy of praise is the transaxle detailing. For example, the gearbox has an internal lever linkage (running through the bellhousing), helping to keep the exterior of the transaxle case clean. It also makes for a relatively straight run and a high level of rigidity. That results in a clean and very precise shift.

The final drive is kept high enough to avoid the usual CV angularity that saps reliability, and the transaxle is very narrow at the final drive, to aerodynamic gain. The inboard CV joints are externally splined to



**The driver's approval: Long Beach winner Danny Sullivan has cause to be grateful for the performance of Alan Merten's Galmer G92 chassis.**

mate directly with the spool or differential carrier. Galmer pays tribute to the role of its Autocad CAD system in facilitating a high level of transaxle design.

However, the car's strongest suit is its aerodynamic efficiency. Low drag for a given amount of downforce was a very significant factor at both Surfers Paradise and Long Beach. IndyCar races are fuel-restricted, and the seaside street races are notoriously heavy on consumption. By turning its lift/drag advantage into engine power, the Galmer was able to take the fight to the impressive new Fords.

Nevertheless, equipped with the outdated Ilmor Chevrolet V8 and making its Indianapolis debut, the G92 was hardly expected to win the 500...







"GALMER HELPED US A LOT," SAYS MIRA aerodynamicist Geoff Carr. "They came to us with a model mounting and balance system for our moving ground plane tunnel that proved a big advance."

That was back in August 1990. Having found improved repeatability of measurement, MIRA decided to install Galmer's Pi Research-produced system on a permanent basis. It is still owned by Galmer Engineering.

Galmer did all its 1991 wind tunnel testing at MIRA, using the largest possible one-third scale model. Described in *Racecar Engineering* Vol 1 No 3, the tunnel has a 6-metre long, 2-metre wide, 1-metre high test section in which a 3-metre long belt runs at a speed of up to 30 metres/second.

The model is mounted via a main centre strut and a thin tail strut (which picks up in front of the rear wing). A two-component (lift and drag) load cell is mounted within the model at the bottom of the main strut, while another load cell measuring lift is set at the top of the tail strut to enable values to be apportioned between the two axes. The wheels are mounted separately on lateral arms which are strain-gauged.

The system permits remote control of ride height, with stepper motors altering the front and rear ride heights individually. It is possible to go through a sequence of 12 ride height combinations without stopping the tunnel. Underside and cooling system pressures are measured by a Scanivalve, a transducer which can read up to 46 data points in sequence.

► the lack of performance from the front wing, and that told as soon as the heavens opened...

Only one revised front wing was available for Phoenix, and Sullivan won the toss. However, both cars were equipped with it at Long Beach. By the time Indianapolis came around, four 1992-spec chassis had been completed. The model was already a winner, Sullivan having taken the Long Beach spoils after tangling with the race leader on the last lap. The race leader, by the way, was Unser Jr...

In road racing trim (see cutaway), clearly the Chevrolet V8 engine Galmer is a formidable contender, even if it does not benefit from the new-generation engine technology represented by the Ford XB, or enjoy the aerodynamic advantage of the slimline 1992 version of the Ilmor engine as used exclusively by Penske. At Indianapolis, the sheer power of Cosworth's XB engine came into its own, even upsetting the revitalised Buick. Pole went to Roberto Guerrero's Buick-Lola at 232.482mph while the Ford-Lolas of Eddie Cheever and Mario Andretti completed the front row, both running over 229.5mph.

The Chevrolet runners were outgunned. Sullivan's Galmer was the fastest of them at 224.838mph, compared with 224.594mph for the next best, Rick Mears's Penske PC21. Unser Jr qualified 12th at an average of 222.989mph. In fact, outside of qualifying Junior had run a 228.055mph lap. Bobby Rahal's Rahal-Hogan team Chevrolet-Lola had

matched that, with the benefit of a tow.

Speed trap figures issued for the Top Ten qualifiers show Sullivan crossing the start/finish line at 234mph on his best lap, which he ran at an average of 226.384mph. He was caught at 224mph in Turn 1, at 221mph in Turn 2, at 234mph at the end of the back straight, at 226mph in Turn 3, and at 221mph in Turn 4.

Comparable figures for Mears's best lap (224.736mph) show the Penske crossing the start/finish line at 229mph, then running at 223mph in Turn 1, at 222mph in Turn 2, at 229mph at the end of the back straight, at 224mph in Turn 3, and at 222mph in Turn 4. The same set of figures for Eddie Cheever's fastest Ford, a Ganassi team Lola, read 234mph at the start/finish, then 228-226-237-231-227mph en route to an overall average lap speed of 230.103mph.

In Speedway trim, the Galmer's aerodynamic efficiency was still apparent. Consider that the Chevrolet pole was stolen from Penske in spite of the team running the larger, older version of the Ilmor V8, and in spite of a handling malady.

The problem was reported as oversteer, but was more accurately one of instability. The Speedway is as close as a race engineer gets to racing in a wind tunnel yet, surprisingly, mechanical grip remains important, mainly in terms of finding a good balance. Prior to the race, Galmer could not find a

good balance. Sweeping off the wall into a turn, the car felt unstable, as if it were about to go loose at the rear.

Understeer, rather than oversteer, is the desired characteristic of Indy, since it makes a car more controllable. If the rear end should break away at 200mph plus, the driver is likely to over-correct and end up in the wall.

The ideal is neutral steer, erring on the side of understeer. The driver should not have to 'drive' into a turn, but he should have to drive out of it. If the car is well-balanced, he will hold it straight on the straight, then relax and let the combination of tyre stagger and asymmetric camber settings take the car into the next turn. An IndyCar is set up with a slight static tilt so that its underwing runs flat through the Speedway's gently banked turns.

Typically, the G92 has a weight distribution close to 40-60 front-rear and, at the Brickyard, runs somewhere between 65-70% downforce at the rear (the exact figure is undisclosed). At 220mph, the car develops in excess of 2800lbs downforce (see panel) and it pulls a sustained 3G-plus on the 9deg banking. To hold it up, the tyre pressures are high and the springs are stiff. Wheel rates are quoted as 2080lbs/inch front and 1700lbs/inch rear.

The high wheel rates help to keep the car stable while, with almost constant-speed running, there is hardly any longitudinal weight transfer. Consequently there is little pitch alteration. The fact that the front wings are kept high off



## PERFORMANCE

**GALMER ENGINEERING AERODYNAMICIST** Andy Brown has released the following representative aerodynamic figures for the Galmer G92:

**Short Oval** 3460lbs downforce at 165mph with 1310lbs drag (L/D = 2.64, Cd = 1.397)

**Street Circuit** 3040lbs downforce at 165mph with 1070lbs drag (L/D = 2.84, Cd = 1.141)

**Speedway** 2835lbs downforce at 220mph with 972lbs drag (L/D = 2.92, Cd = 0.669)

Note that fuel consumption is higher on a street circuit such as Long Beach than on a short oval such as Phoenix; consequently the car has to be set up so as to pull less drag. By way of comparison, in the days before cab roof fairings a Cd of 1.0 was a typical figure for a high-drag truck. These days, trucks are down to the region of Cd = 0.6.

The figures quoted for the 1991 Indy 500 winning Penske PC20 in its Speedway trim (Vol 2 No 2) were 3010lbs downforce at 220mph with 1075lbs drag (L/D = 2.80).

Brown comments: "I'm always a little cautious of comparing figures from different wind tunnels, because experience has shown them all to vary slightly. The L/D is usually close, though, and I'm pleased to see that ours is marginally better than that quoted for the PC20. Provided we're both telling the truth, that is!"

the ground by the regulations further contributes to the stability of the centre of pressure.

Running a high proportion of downforce at the rear assists stability and tends to induce understeer (as does running a softer bar at the rear than at the front). Running a spool likewise helps to promote understeer. A touch of understeer helps to give the driver the confidence he needs to lap the track without lifting the throttle.

Lapping the track without a lift naturally becomes harder as the downforce is progressively backed off so as to minimise drag. This is taken to extremes in qualifying. It highlighted the Galmer's instability, but the instability was still there in race trim on Carburation Day. Held the Thursday before the race, Carburation Day was hot: the hotter the track, the more pronounced the instability.

"We were all pretty po-faced after Carburation Day," Mertens recalls. During their long time working together, he and Junior had gained something of a reputation for eleventh-hour changes in times of need – but to modify the car on the eve of the Indy 500 would be a massive gamble.

Mertens felt the root of the instability was the rear suspension geometry. He thought that a geometry change might be worthwhile. He felt that he knew which aspects of the car would be hurt by such a change, and he was confident that he could alter springs and dampers to compensate. But he couldn't know

what it would do to the balance.

Mertens and Junior eventually agreed that it was worth a try, given that they had seven pitstops ahead during which to work on the balance through tyre and wing adjustments...

The blocks picking up the rear lower wishbones were changed so as to alter the location of the pickup points. Since it was a gamble, only Unser's car was modified. Happily this untested geometry modification worked, giving the car much better stick at the rear. The cold weather of race day also helped. With the revised geometry, the rear end had settled down to the extent that Unser found excessive understeer at the start of the race.

Through the race, the initial understeer was reduced by playing with tyre pressures and stagger and by altering the front wing angle and switching the rear wing Gurney tab. Careful detail design of the G92 chassis permits rapid changes of flap angle and Gurney during routine pitstops.

By mid-race, Unser's understeer was well under control and he was heading the Chevrolet brigade. All along, Galles-Kraco knew that it could not challenge for better than 'Top Chevrolet', and the policy had been to do the best possible job with an outdated engine, rather than to go for broke in a futile chase of the hares.

In fact, Unser has always favoured the policy of running carefully for all but the last 10% of the race, trying only to stay on the lead lap while nursing his equipment. This year, of course, the engine was well proven while the team was confident of the reliability of the Galmer chassis: it had not broken in six previous race starts.

There had been a scare over pinion temperatures earlier in the month, but that had been solved through a revision of the internal oil galleries in the gearbox. There had also been a spate of slow punctures – traced to an over-enthusiastic Goodyear technician's temperature probe! The team had also been seen to suffer a high number of engine failures, but those had not surprised it, given the strain the track puts on engines and its policy of using high-mileage units prior to the race.

That both Galmer cars finished the 500 miles was not unexpected. However, given the level of attrition as the cold track caught out driver after driver, and accident debris worsened the situation, any finisher this year could count themselves somewhat lucky. By two-thirds distance, almost two-thirds of the field was sidelined, and an unlucky 13 drivers had suffered accidents.

Thereafter, as Michael Andretti stroked towards a comfortable win for Ford, Lola and Newman-Haas, Unser Jnr had the speed and reliability to win the race for second place. Sullivan had lost a lot of ground when his second set of tyres induced excessive understeer. Without the rear suspension geometry modification, his car was much more of a handful in traffic.

## ON TRACK

At the penultimate round of pitstops, Unser did not change tyres and that cost him on the run into the finish. The rears wore so thin that the car started to oversteer and, by the time the final round of pitstops came around, Scott Goodyear's Walker team Chevrolet-Lola and Al Unser Snr's Menard Buick-Lola were in the hunt for second place.

Unlike the Unsers, Jnr and Snr, Goodyear did not need new tyres at the last stop. Father suffered a bungled stop which, as it turned out, probably cost Buick's chance of victory. His car was at rest 5 seconds longer than his son's, and left with incorrect tyre stagger.

Junior also left the pits behind Goodyear, having taken on a set of 'stickers'. Brand-new tyres give more grip initially, but tend to go off sooner. It was a gamble.

The Galmer was faster in a straight line than the Walker Lola ahead, partly because Goodyear was running more downforce for a more comfortable drive. Junior took him in traffic on lap 188 (of 200), and Andretti's shock retirement occurred on lap 189. That prompted a caution which lasted until lap 193: a seven-lap fight to the finish.

On lap 197, Unser's tyres did indeed go off, and he had to make his car very wide indeed. The Galmer was loose in Turns 3 and 4 and, on Turn 4 on the very last lap, Unser felt he needed a slight lift to ensure he got through. Goodyear didn't need to lift, and all but overtook the Galmer at the line, in the closest finish in the history of the 500-mile race.

Unser Jnr had the win he desired above all. And Alan Mertens now had something else in common with Colin Chapman and Bruce McLaren... ■

## GALMER G92: SPECIFICATION

**Marque** Galmer **Model Designation** G92 **Producer** Galmer Engineering **Specification Date** May 1992 (Indianapolis 500)

### COMPONENTS

**Chassis** Carbonfibre monocoque **Engine** Chevrolet Ilmor V8, fully stressed **Transaxle Case** Magnesium with outboard longitudinal gearbox **Gearbox** 6-speed, non-synchro **Clutch** Sintered 7 1/4-inch triple-plate **Differential** None (spool) **Driveshaft** Steel with CV joints **Front Suspension** Pushrod **Rear Suspension** Pushrod **Dampers** Gas **Wheels** Magnesium one-piece, 15-inch diameter **Brake Discs** Carbon-carbon, outboard **Callipers** Single, 4-pot **Water Coolers** Two, pod-mounted **Oil Coolers** One, heat exchanger **Oil Tank Location** Fuel tank area **Fuel Tank** Single-cell, 40 US gallons **Fuel Tank Location** Central **Bodywork** Carbonfibre **Dry Weight** 750kgs **Wheelbase** 111ins

### SUPPLIERS

**Chassis Fabrication** Advanced Composites **Dampers** Koni **Wheels** Dymag **Brake Discs** Hitco **Callipers** Alcon **Pads** Raybestos **Master Cylinders** Alcon **Clutch AP Fuel Cell** Goodyear **Water Cooler Cores** Secan **Oil Cooler** Secan **Tyres** Goodyear **Fuel Valve** Valvoline **Oil** Valvoline **Brake Fluid** Castrol/AP **Transaxle Case** Casting Stone **Foundries** Bodywork Advanced Composites **Springs** Hyperco **Steering Rack** Jack Knight **Rod Ends** Goldline **Fasteners** Tridair, Camloc **Wheel Bearings** INA, NTN **Master Cylinders** Alcon **Hoses** Aeroquip **Gears** Xtrac, Emco, Hewland **Differential Case & Spool** Pankl **Differential Internals** Emco **CV Joints** Superboot **Fuel Couplings** Symmetrics **Fuel Pump** Ilmor **Exhaust** Parallel Motions **Alternator** AC Delco **Battery** AC Delco **Data Acquisition** Pi **Telemetry** Pi **Steering Wheel** Racetech **Seat Belt** Willans **Instruments** Pi **Radio** Radius/Motorola **Extinguishers** Lifeline



THE FLOOR PANEL ACCESSED MONOCOQUE of Alan Mertens's Galmer G92 is produced from carbonfibre moulds and comprises carbonfibre skins over aluminium honeycomb. Following regular IndyCar practice, the rear bulkhead is detachable to provide access for the near-rigid fuel cell. The front bulkhead is integral and carries the master cylinders via an aluminium insert. An extension of that insert carries the pedals. Two aluminium bulkheads help support the front suspension – mid-front and mid-rear – while composite dash and seat back bulkheads complete the internal dividers.

The fuel tank area splays wider than the cockpit at sidepod level to help keep its liquid load low. The oil tank occupies a thin but tall section of the fuel tank area adjacent to the rear bulkhead. The 40-gallon Goodyear fuel cell is shaped to fit around the oil tank and the gear linkage. It incorporates internal baffles and flaps to Galmer's specification. Fuel is lifted by an engine-driven pump that sits on top of the fuel tank area of the monocoque, shrouded by the roll-bar fairing.

Prior to painting, the monocoque weighs 52kgs. While it forms the cockpit coaming, the faired-in roll hoop is detachable. A steel hoop is shrouded by a composite fairing and the combined structure is bolted to the top of the fuel tank area.

The nose is another carbonfibre-over-aluminium structure and its open rear slots over a flange formed by the front bulkhead. Internally the nosebox is divided into two by a longitudinal splitter that improves crash resistance.

Limited in terms of both size and positioning by Speedway regulations, the high-mounted, single-element front wing is tiny and acts primarily as a trim tab. Each side of the wing slips over a steel spar that passes through the nosebox.

The single-element rear wing is firmly bonded to twin plates that attach to the gearbox with a rapid-adjustment facility to alter the angle of attack from that position. The wing carries a Gurney tab that can be quickly slid out and replaced.

The full-width underwing (incorporating the mandatory flat bottom area) forms the lower section of each pod, while the top sections are integral with the engine cover. The underwing supports the water radiators, while their intake ducts are hung off the monocoque and are formed as separate upper and lower sections. The radiator exit duct is integral with the top of the pod and incorporates an adjustable shutter that slides open to provide additional cooling, at the penalty of increased drag.

The wings, underwing and bodywork are carbonfibre-over-aluminium honeycomb. Since weight is not a problem at Indy (thanks to the lightweight wings, the carbon-carbon brakes and a titanium spool), a hefty stainless steel skid plate covers the regulation flat-bottom area.

The G91's advanced composite work was done by Comtec in the factory next door to Galmer Engineering. Following the collapse of Comtec, in January Galmer turned to Advanced Composites, which is based near Derby. For the G92, Advanced Composites altered certain aspects of the layup, claiming improved structural integrity as a consequence.

Attached to the rear of the monocoque, the engine is fully stressed and carries a bespoke magnesium transaxle case produced by Stone Foundries. The gearbox is outboard and longitudinal, with the input shaft running under the crownwheel and pinion and the pinion at the front of the output shaft.

The bellhousing is detachable and sits the turbo just above a pair of step-gears which take the drive up from the clutch to the right height, so that the two-shaft gearbox sets the pinion close to the centreline of the rear axle. The aim is to keep the crownwheel and pinion high enough to avoid significant driveshaft angularity. The angle through which the CV joints have to run dictates the ball displacement and velocity which, in turn, determines the longevity of the joint.

The bellhousing is stiffened by a bolt-on aluminium casting which sits over the turbo and helps to support the turbo and the suspension. Modified for a twin entry to the compressor, the turbo is carried by three ball-jointed adjustable links. Apertures in the bellhousing assembly provide passage for the turbocharger plumbing.

The bellhousing forms the front half of the final drive housing, the rear half being formed with the gearbox main case. The base of the transaxle case is upstepped to the rear to maximise the scope for diffuser design. All stiffening ribs are internal to keep the outside of the case as clean as possible, while the detachable rear bearing carrier keeps the selector mechanism inside the casing, and on one side.

The gearshift linkage runs forward through the main case and bellhousing, then through the fuel tank area of the monocoque. The six-speed gearbox is an evolution of the unit that Mertens designed at March in the early 1980s specifically for IndyCar racing. Its chief characteristic is a so-called 'strap', an additional bearing carrier positioned between the heavily loaded second and third gears to provide additional support for the shafts.

The step gears in the bellhousing provide an easy means of varying the final drive ratio. Fed from a cable-operated AP triple-plate, 71-inch sintered clutch, the gearbox has conventional (non-synchromesh, dog selection) internals manufactured by Xtrac, and feeds out through the titanium spool (a solid link between the driveshafts). The driveshafts are maraging steel and are equipped with Lopro-type CV joints.

The gearbox is dry-sumped with its oil reservoir in the bellhousing. The pump is in the main case and is driven off the input shaft. An oil cooler is mounted on the end cover that closes the transaxle case. A carbonfibre shroud over the cooler picks up air flowing between the twin wing-mounting plates. The end cover carries the wing mounts and also an air jack (the monocoque carries twin forward jacks).

The rear suspension is kept above the diffuser. It is supported by the transaxle, with the aluminium casting on top of the bellhousing carrying the pushrod rockers, the spring damper units and the anti-roll bar. The aluminium casting also forms a clevis which picks up the forward leg of the upper wishbone. Spacers permit easy adjustment of geometry.

The rear leg is picked up by an aluminium block attached to the main case; alternative blocks permit further alteration of geometry. Similar blocks pick up the rear leg of the lower wishbone and the inboard end of the track control arm. The forward leg of the lower wishbone is picked up by an L-shaped aluminium mount which bolts to the engine and also to the bellhousing.

At the front of the car, the forward leg of the upper wishbone is picked up by a steel fabricated mount that wraps around the front of the monocoque. The rear leg is picked up by a machined aluminium block that attaches to the mid-rear bulkhead and the mono-

coque side. The rear leg of the lower wishbone is picked up by an aluminium beam bonded into the dash bulkhead, while the forward leg is picked up by the aluminium insert that carries the master cylinders and pedals. Again, the mounts provide for geometry alteration.

The pushrod rockers of the front suspension pivot between the mid-front and mid-rear bulkheads, which also support the spring/damper units. Mounted over the driver's shins, the spring/damper units are positioned at an angle rather than directly upright, for a rising-rate effect. There is no rising-rate at the rear. Front and rear suspension adjustment provides for anti-dive and anti-squat to be varied within the range 0-50%.

An anti-roll bar is mounted on the mid-rear bulkhead. Both front and rear bars are steel and are activated by short links from the steel fabricated pushrod rockers. These links take the form of blades with the facility for cockpit adjustment.

Front and rear, steel springs are mounted over Koni dampers. The wishbones and pushrods are steel, aero-section tubing being employed for the most of the wishbone legs. The upper front wishbones are formed from tube which is specially rolled to create the desired aerodynamic profile.

The front and rear uprights are steel fabrications carrying outer roller bearings and inner deep-grooved ball-bearings. Steel hubs have a bearing track machined into them. The uprights incorporate galleries to duct air over the bearings and to the eye of the disc. The cooling efficiency is claimed to be very high.

Six titanium pegs screw into a flange on the hub to locate the aluminium disc bell and the one-piece Dymag magnesium wheel. The 12.875-inch diameter discs are Hitco carbon-carbon stopped by Alcon four-pot calipers. No brake ducting is provided and the wheel assembly is closed by a flush fitting outer cover, for minimum drag. The wheels are of 16-inch diameter, 10.75-inch wide at the front, 15-inch wide at the rear. The front tyres have a diameter of 25.5-inch, the rears of 27.0-inch.

The steering rack has a seven-tooth pinion and is by Jack Knight in a Galmer fabricated steel housing. The assembly is bolted to the mid-rear bulkhead, the steering arms rear facing from the upright.

The electrics are located in the righthand pod: the ECU, the spark box, a Pi data-logger and an AC Delco battery. In the corresponding space in the lefthand pod sits a Secan oil/water heat exchanger. The single water radiator each side has a Secan core. Air is permitted to pass between the side of the radiator inlet duct and the side of the monocoque to provide cooling for the engine bay, including the electrics.

An aperture in each flank of the engine cover provides the unusual twin feed to the compressor. Air is encouraged into the aperture by the shape of the bodywork. The only other fuselage intake is a NACA duct formed in the cockpit coaming to provide a driver cooling feed. A small air deflector lip takes the place of a windscreen.

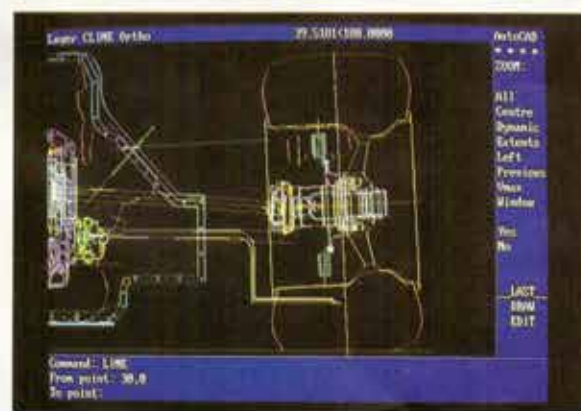
The driver's helmet is flanked by an add-on head restraint on the right-hand side to help him keep it upright. He is in radio communication with the pits. The instrumentation is Pi digital and there is a Pi telemetry system transmitting engine and chassis data.

Chassis data acquisition sensors can include underwing pressure taps, pushrod strain gauges, and even an undisclosed ride-height sensor.



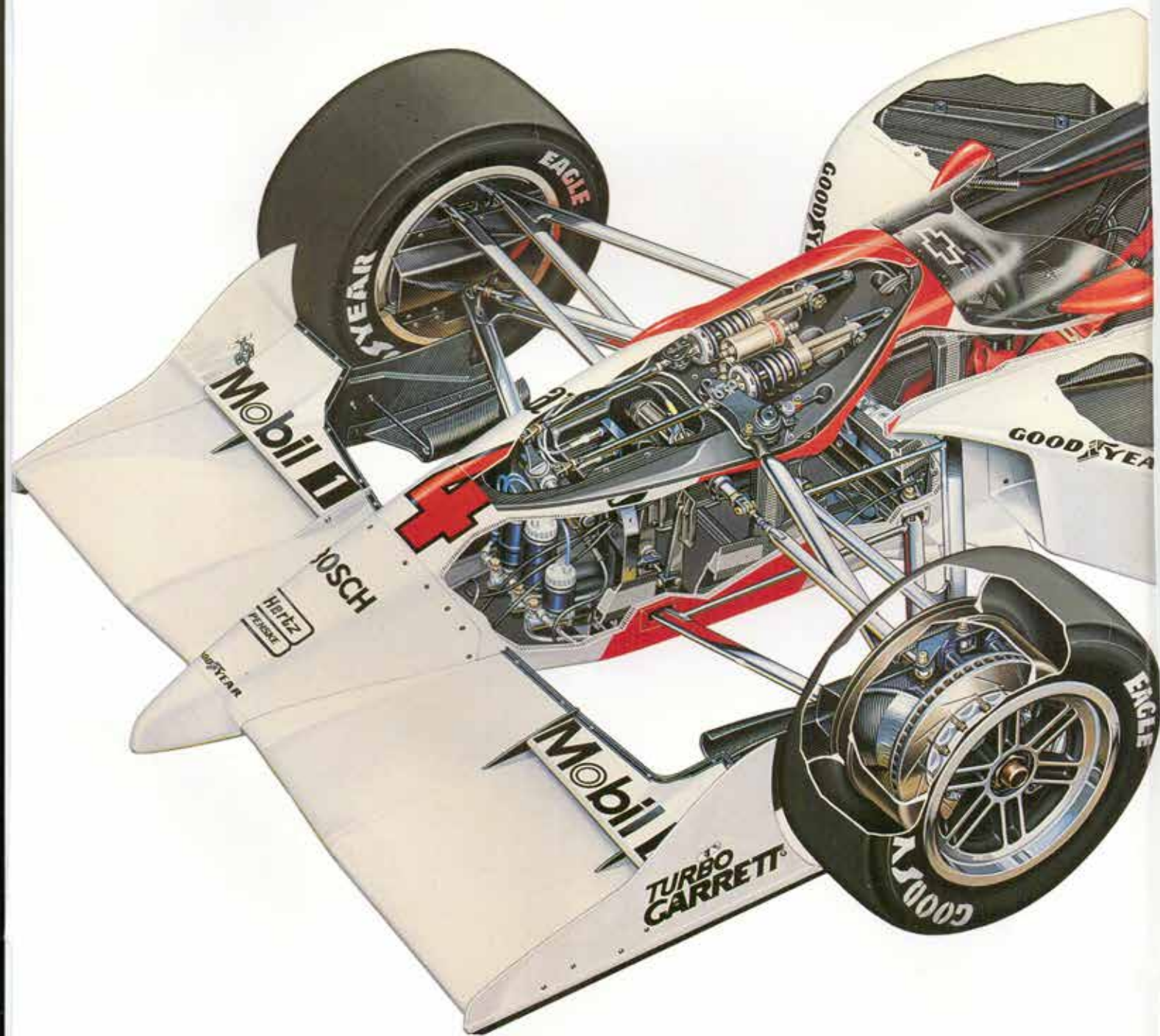


Details of the G92 chassis, which carries Galmer's own transaxle (above). The G92 was designed using Autocad software (right) and features exhaust activation of both diffuser tunnels (below). The cockpit (left) is equipped with PI instrumentation.

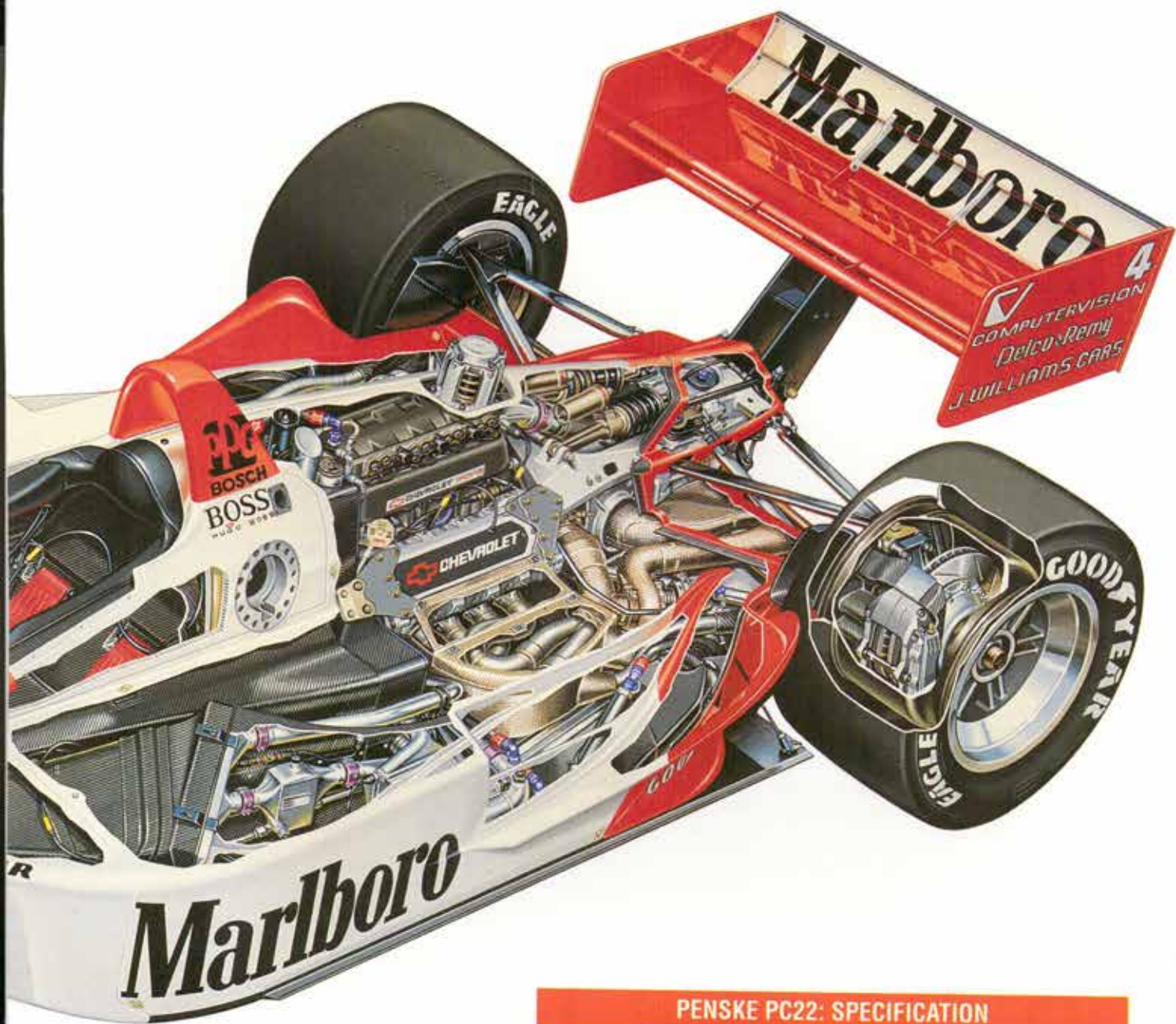




 **CHEVROLET**







## PENSKÉ PC22: SPECIFICATION

**Marque** Penske **Model Designation** PC22 **Producer** Penske Cars **Specification Date** March 1993

### COMPONENTS

**Chassis** Carbonfibre monocoque **Engine** Chevrolet Ilmor V8, fully stressed **Transaxle Case** Aluminium alloy with inboard transverse gearbox **Gearbox** 5/6 speed, non-synchro **Clutch** Sintered 5.5-inch triple-plate **Differential** Undisclosed **Driveshaft** Steel with CV joints **Front Suspension** Pushrod **Rear Suspension** Pushrod **Dampers** Gas **Wheels** Magnesium one-piece, 15-inch diameter **Brake Discs** Cast-iron, outboard **Brake Calipers** Single, 4-pot **Water Coolers** Two, pod-mounted radiators **Engine Oil Coolers** One, heat exchanger **Oil Tank Location** Fuel tank area **Fuel Tank** Single-cell, 40 US gallons **Fuel Tank Location** Central **Bodywork** Carbonfibre & Kevlar **Dry Weight** 703kgs **Wheelbase** Undisclosed

### SUPPLIERS

**Engine** Ilmor **Engineering** **Turbocharger** Garrett **AiResearch** **Oils** Mobil **Plugs** Bosch **Fuel Cell** Lorai **Gearbox** Xtrac **Transaxle Case** Kent Aerospace **Castings** Castings **Clutch** AP Racing **Master Cylinders** AP Racing **Wheelbearings** SKF **Driveshafts** Metalore **CV Joints** Metalore **Dampers** Penske Racing **Shocks** **Wheels** Kent Aerospace **Castings** **Tyres** Goodyear **Brake Discs** Alcon & (carbon-carbon) Hilco **Brake Calipers** Alcon **Brake Pads** Performance Friction & Hawk **Water & Oil Coolers** Modine **Auto-Cool** **Aerofoils** DPS **Rod Ends** NMB **Fasteners** Dzus **Battery** AC Delco **Radio** AC Delco **Data Acquisition & Instruments** Pi Research **Telemetry** AC Delco & Pi Research **Electrics** AC Delco & Pi Research & Ilmor **Steering Wheel** Personal **Seat Harness** Willans **Fire Extinguisher** Lifeline





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## PENSKE PC22 INDYCAR



By IAN BAMSEY

**T**he 1993 Penske PC22 IndyCar is the equipment exploited by Penske Racing drivers Emerson Fittipaldi and Paul Tracy, and also by Bettenhausen team driver, Stefan Johansson. At its heart is the latest Chevrolet Ilmor 265C, turbo V8, 2.65-litre engine. Tony Matthews's cutaway overleaf depicts the PC22 in its road racing trim, as described here.

The PC22 has the usual central fuel tank and carries this potent engine fully stressed. It has pushrod operation of its twin coil-over-damper suspension units, with the front suspension carried by an advanced composite monocoque, the rear by a structural transaxle case. Within that case, a transverse gearbox is located ahead of the final drive. The car is ballasted to achieve the mandatory minimum weight of 1550lbs (704.5kgs).

The monocoque sets carbonfibre and Kevlar skins over aluminium honeycomb. Made in two halves, with a central horizontal split about 7-inch above the floor, the main shell includes an integral front bulkhead. The rear bulkhead is detachable for access to the regulation semi-rigid fuel cell. Seat back, dash and steering rack bulkheads are of the same material as the shell, but the pedal bulkhead is a magnesium casting.

Mounted over the scuttle, the front spring/damper units and the pushrod rockers operating them are carried by a separate carbonfibre moulding, bonded to the main shell. The top wishbones are picked up by titanium brackets attached to the outer shell and the adjacent bulkhead. The front legs of the lower wishbones are picked up at the ends of a machined-from-solid aluminium beam, attached to the adjacent bulkhead. The same system mounts the rear legs.

The rollhoop is a separate moulding, forming a shroud over the regulation 1.375-inch diameter, 4130-steel tube structure atop the fuel tank housing. The front bulkhead forms a flange to which the nose is bolted, via more than 20 bolts. Made from the same material as the monocoque shell, the composite nosebox shapes the front of the fuselage. The front wing is bolted to its underside via two vertical bolts and can be substituted in only 15 seconds.

The rear wing is mounted on twin aluminium plates which also carry the rear anti-roll bar and are picked up by the end cover of the transaxle case. This

is a thinwall aluminium casting with the bellhousing separate from the gearbox case. The latter is closed (aside from the end cover) by a side cover that gives access to the ratios.

For road races, the PC22 is equipped with a sequential change, transverse gearbox, with five speeds plus reverse. It is fed by a 5.5-inch sintered metal clutch.

The turbocharger, rather than the oil tank, sits in the bellhousing, to keep its considerable weight as low as possible. It has single entry and exit, the exhaust discharging between the rear deck and the diffuser (exhaust gas cannot be fed into the diffuser). The big turbo unit nestles behind the clutch and the rear airjacks, over the gearbox input shaft, and is enclosed by an overhead bridge piece. This bolted-in aluminium casting adds to transaxle stiffness, and takes loads forward from the rear suspension to the engine.

The rear suspension spring/damper units and the forward legs of the upper wishbones attach to the bridge piece, while the gearbox case picks up the other wishbone legs and provides the mounts for the pushrod rockers. The lower wishbones attach directly to the case, while the upper wishbones are picked up via blocks which permit alteration of suspension geometry.

Both front and rear, the suspension employs three-way adjustable gas dampers, wrapped by steel coilsprings. All wishbones and pushrods are fashioned from aero-section 4130 steel tube while the pushrod rockers and the uprights are 4130 fabrications.

The wheelbearing system is undisclosed. Magnesium wheels are cast to a Penske design and are driven by six pegs. The steering is rack and pinion with a rack produced in-house. The brakes employ internally ventilated, cast-iron discs, as per the regulations, with four-pot aluminium calipers.

Both front and rear brakes are serviced by cooling scoops which feed into the back of the respective upright. The rear bodywork contains a NACA duct which cools the exhaust system, wastegates and clutch. The water and oil coolers are fed from an intake at the front of each sidepod and the air exhausts through the pod lid, just ahead of the rear wheel. Inside each pod is a separate radiator intake duct which is permanently attached to the monocoque. The exit ducting is formed by the sidepod.

Each cylinder bank feeds into its own

upright water radiator, but the return to the engine is through a single pipe into which are plumbed both an oil:water heat exchanger for the engine and a smaller oil:water heat exchanger for the gearbox. The heat exchangers are both located on the left-hand side of the chassis, behind the left bank water radiator. Each water radiator sits well forward in its pod. Further back, the fuel tank flank splays outwards under the pod cover. The fuel cell has internal baffles to Penske's design. Fuel is picked up by a mechanical pump that has a cable drive off a camshaft. The engine oil tank is made in-house from aluminium and forms a vertical tube of undisclosed capacity, sited within the fuel tank area, between the cell and the rear bulkhead.

The forward section of each sidepod is formed together with the undertray. The rest of the pod is formed with the rear cover which incorporates the fuel tank and engine shroud. Aside from a detachable scuttle cover for spring/damper access, the combination of nosebox and monocoque shapes the front of the fuselage, including the cockpit surround. However, a polycarbonate moulding forms a cockpit air deflector.

The undertray is one-piece and forms the underwing from the leading edge of the sidepods to the end of the diffuser, aside from the mandatory flat area, which is formed by a skidplate attached to the base of the monocoque. The skidplate is metallic, while the underwing and the bodywork is advanced composite. The skins are carbonfibre with some Kevlar, and the cores are Nomex honeycomb, with aluminium honeycomb in areas of the underwing that are subject to exhaust heat.

Penske Cars makes its own air jacks. The front jacks are located alongside the seat, putting them the same distance from the centre of gravity as the rear jacks.

The sparkbox is sited in the left-hand sidepod, with the heat exchangers. The other electrical boxes are located in the right sidepod, with the battery. The PC22 carries Pi System 4 Plus data acquisition, with an instrument binnacle made by Pi to Penske's requirements.

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## PENSKE PC22 INDYCAR

The elegant Penske PC22 Chevrolet is the car that Nigel Mansell is likely to find hardest to beat over the balance of the 1993 PPG IndyCar World Series. Exploited by a powerful blend of youth, speed and experience in the driver pairing of Paul Tracy and Emerson Fittipaldi, Penske Racing's new 1993 challenger is equipped with the latest Chevrolet Ilmor 265C engine, which looks a match for the Ford Cosworth XB. The season began with the Penskes running 1-2 at Surfers Paradise and again at Phoenix, and then Tracy won the first IndyCar victory of his career in the Long Beach GP. Armed with the PC22, Tracy and Fittipaldi are definitely

veable and maybe had more torque, if less top-end power," he says. Engine performance continues to improve with the 265C, the use of which is not exclusive to the Penske team.

The 265C reverts to a smaller plenum thanks to a different configuration of intake system. Some 2-inch lower than the 265A, it is smaller again than the early-season 265B in cross-section through the cam covers and plenum chamber. This has permitted a significant slimming of the dorsum, to the benefit of the airflow to the rear wing. The slimmer dorsum means reduced capacity in the upper region of the fuel tank area. Consequently, while of the same length, width and overall height, the PC22 tank is a little taller in its flanks which extend under the sidepods. The net effect is a slightly lower centre of gravity for the fuel load.

Consistency of performance from full to empty tanks was a problem on short ovals in 1991, Bennett acknowledges, adding that the mechanical balance of the PC20 was less than perfect. However, Bennett observes, "In 1992 the PC21 was appreciably better. We did little to it - it won five races and ended the season in an almost identical specification to the one it started out with."

Because the the PC21 carried between 50-90lbs of ballast, the team was able to investigate the effect of changing the weight distribution. "In the new car," Bennett says, "the weight distribution has been adjusted in the direction we found last year's PC21 wanted..."

Of course, new technical regulations affect the architecture of the chassis. In particular, this year an IndyCar chassis has to be at least 5.0-inch longer ahead of the pedal bulkhead. Overall, the car has to be a minimum of 190-inch long, whereas last year's designs were not permitted to exceed 185-inch.

Bennett is unwilling to divulge the wheelbase of the PC22. He will only say that it is different to that of last year's PC21. The PC20 of 1991 had a wheelbase which varied between 111-inch and 114-inch via the substitution of front wishbones, the longest throw being employed on a SuperSpeedway. The PC21 also had a longer wheelbase at Indianapolis, but that 114-inch dimension was retained for the balance of the season. This year's PC22 has a fixed wheelbase which, in view of the new regulations, we believe to be longer still.

Like the length of the fuel tank, ▶

# GUNNING FOR MANSSELL

**T**he Penske PC22 is produced, like all Roger Penske's racecars, at the Poole, Dorset factory of Penske Cars in south-west England, and operated by Penske Racing out of Reading, Pennsylvania, in the eastern USA. As evidenced by its on-track performance at the start of the IndyCar World Series, Penske's chief designer has made substantial progress with his PC22. "This is less of an evolution than anything I've done here so far - as big a change as from the PC16 to my first Penske, the PC17," Nigel Bennett affirms.

Acknowledging that his thinking is ever evolutionary, Bennett points to fresh features such as the PC22's clean-sheet-of-paper monocoque design, which sets the spring/damper units over the scuttle for the first time. At the rear of the chassis, the transaxle casing is equally new. In conjunction with a revised rear suspension layout, it permits a more efficient underwing form.

The front wing is also revised: in road racing trim, the PC22 retains only the rear wing package from 1992. In spite of this year's bans on flush-faced wheel rims and diffuser fins, Bennett has found a significant improvement in

aerodynamic performance. Aside from better lift and drag figures, the PC22 water and oil cooling system is more efficient. Bennett: "Problems of oil tank performance and fuel pickup have been addressed with the new car."

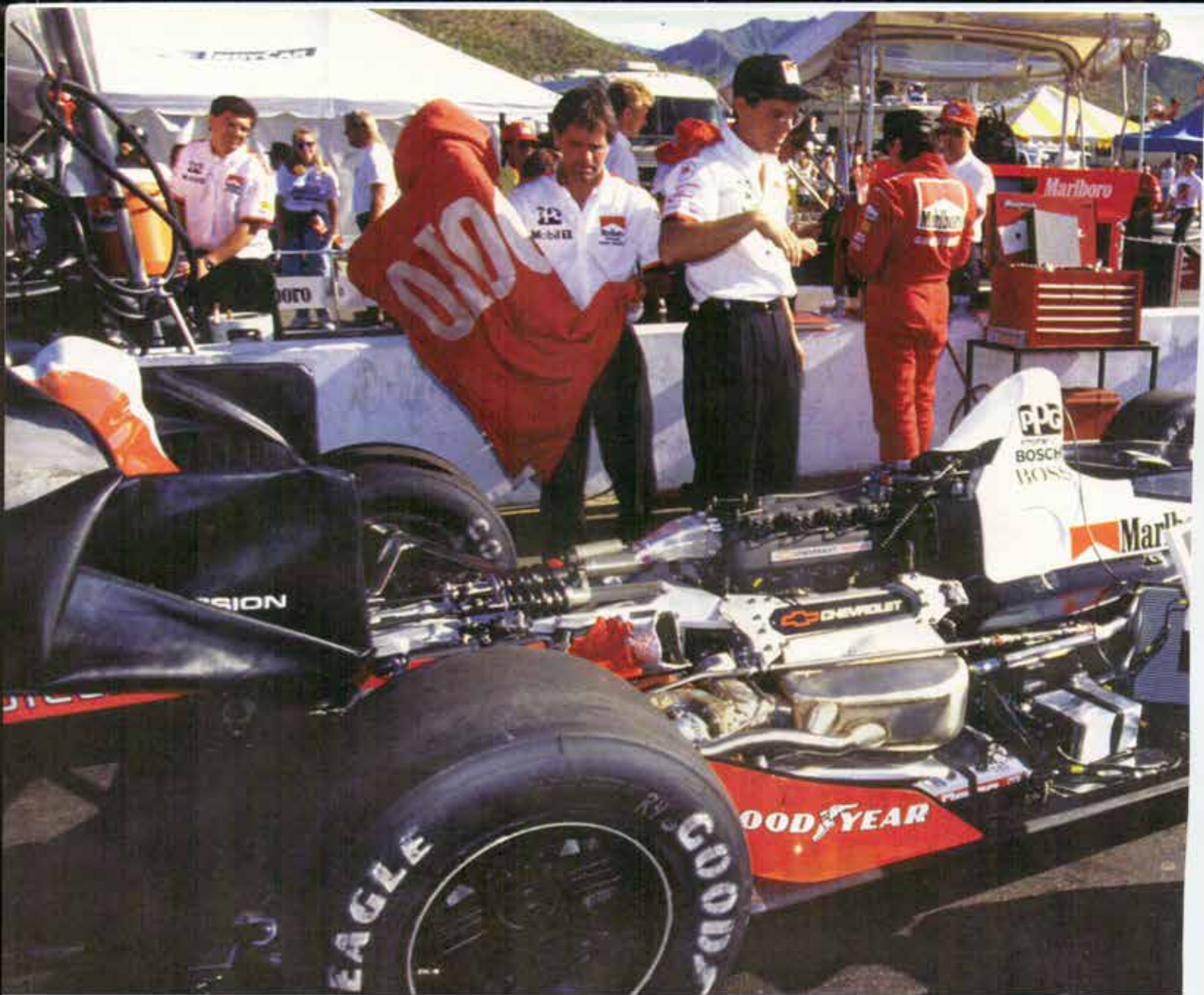
In addition, the PC22 gearbox has the mechanical sequential change introduced at the end of 1992, while suspension geometry tested last year has also been incorporated. More significantly, the wheelbase length is new. And even the engine is new.

The PC22 carries the third generation of Chevrolet Ilmor 265 engine, which is smaller and lighter, and has a lower centre of gravity than its predecessors. Last year's PC21 carried the second generation of an engine introduced in 1987. While quite a bit lower than the original unit, in mid-season the 265B was fitted with a taller plenum. This cost aerodynamic performance but gave a performance gain that more than compensated.

Over the first half of the 1992 season, the Ford Cosworth XB had been a markedly more powerful engine than the 265B. Nevertheless, Bennett reckons that, by the end of the year, the 265B was the better road race weapon of the two. "Our engine was more dri-

Penske Racing has a classy driving team in Paul Tracy (top) and Emerson Fittipaldi, an effective chassis, and a promising engine in the latest Chevrolet C, which is the heartbeat of the Penske PC22.





► the length of the driving compartment is unchanged with the PC22, according to Bennett, the driver reclining to the same degree as last year. IndyCar regulations keep the pedals behind the front wheel axis. Given the shorter engine and a longer wheelbase, extra length might well have been added to the transaxle – which sets the gearbox ahead of the final drive – as well as to the front of the chassis.

Although the 265C engine is lighter than its predecessors, the latest regulations make Penske's chassis structure heavier. Bennett reveals that extra material in the PC22 monocoque adds over 20lbs. In addition, beefing up of the transaxle has added weight in that area, one in which ballast was previously carried. In spite of this extra chassis weight, the car still requires 15-20lbs ballast in road racing trim.

An IndyCar typically has close to a 40-60 front-rear static weight split, with the centre of gravity within the fuel tank. Bennett notes that the static weight distribution of the PC22 "can be different" from that of the PC21, according to the location of the ballast. He adds that the fore-aft location of the centre of gravity does not necessarily



follow the location of the centre of pressure, which significantly varies as the aerodynamic package is adjusted to suit different types of circuit.

#### Aerodynamics

Last year's PC21 had six splitters or fins, these sub-dividing the diffuser into seven channels. Drag-reducing flush

At Phoenix (top), Surfers Paradise (above) and Long Beach, the PC22 chassis looked better than the latest Lola, come race day.

rims were frequently used. "We fitted them everywhere we could," says Bennett. "On some road circuits we had to leave them off at the rear in the interest of brake cooling."

Penske Cars works in the larger of the two scale-model wind tunnels at Southampton University, running a 40% replica on a moving ground plane.



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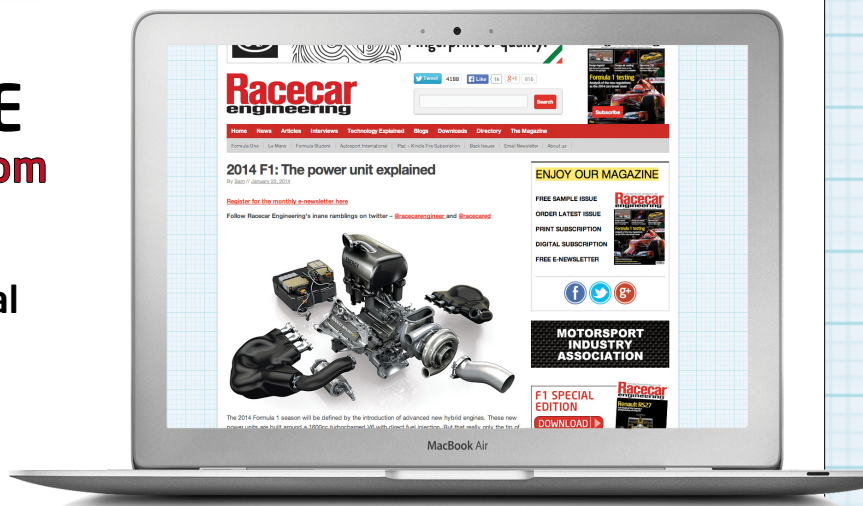


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Tests conducted on the model of the 1992 car showed that the loss of fins and flush rims cost 2% downforce for a given level of drag, or 2.6% more drag for a given level of downforce.

The performance of the 1993 aerodynamic package is affected by the increased car length and the slimmer dorsum, the former theoretically adding downforce, the latter certainly enhancing rear wing performance. The modified transaxle shape, in conjunction with other changes, has also improved the aerodynamic performance of the car.

Although he has revised the front wing, Bennett has retained the anhydral form he introduced last year. He has raised the nose slightly more than in 1992 – but still very little, not as much as is permitted, even under the more restrictive ruling introduced this season. He comments: "You want the best airflow under the central part of the car as you can. That doesn't necessarily mean you must raise the nose as far as you can..."

Thus, the PC22 front wing is a development of the PC21 wing. Each side, it has a single adjustable flap plus an optional, adjustable Gurney and twin

**Work in progress at Poole last November with Nick Goozée to the left of the PC22 monocoque.**

endplates. The wing's inner endplates extend back between the tyres to form vortex generators.

Vortex generators are also mounted at the sidepod intake, as on previous models. "They create significant vortices," admits Bennett. "We are trying to keep the flow attached up the tunnel. A vortex helps that. And it has a low-pressure core, which gains us additional downforce."

With the modified transaxle form and the loss of fins, the underwing has been fundamentally altered for the PC22, whereas the three 1992 road race/short oval rear wing options are carried over. Conforming with the regulations, the rear wing is single-tier and is sandwiched between endplates of a mandatory maximum size. It has adjustable flaps and Gurney.

Aside from front and rear wing flap angles and Gurneys, the angle of the flaps at the end of the tail deck can be altered to change the aerodynamic characteristics of the PC22. Of course, there is an alternative SuperSpeedway package, as described later.

With rising engine power, the cooling capacity of the PC21 became marginal. The PC22 boasts 10% more ▶

## INDYCAR v. F1

FOLLOWING THE MUCH-PUBLICISED defection of the Formula 1 World Champion to IndyCar racing, the European media have highlighted the differences in driving styles that are demanded by the world's two leading single-seater racecar categories. The fundamentals are these. The 1993 F1 car is powered by a 3.5-litre, atmospheric engine (V8, V10 or V12), while the 1993 IndyCar is equipped with a 2.65-litre, forced induction V8. Each type of engine develops either side of 750bhp but, while the F1 car must weigh at least 505kgs (1111lbs), the minimum weight of the IndyCar is 705kgs (1550lbs). The power/weight ratio of the F1 car, therefore, is far superior.

To control power outputs, IndyCar regulations restrict turbocharger size, ban aftercooling, and dictate that the plenum chamber is fitted with a pop-off valve designed to restrict intake pressure to a maximum of 45-inch of Mercury (1.53 bar) absolute.

Unlike F1 cars, IndyCars use methanol fuel. Races range from 165 to 500 miles in length and there is a total fuel allocation calculated on the basis of 1.8 miles per gallon. The maximum fuel tank capacity is 40 US gallons, so a car must be refuelled half a dozen times if it is to utilise the maximum allowance for a 500-mile race.

There are a multitude of other differences, of course, and many of them do also affect the driving requirements. In road racing trim, for example, the aerodynamic package of the IndyCar suffers a certain amount of pitch sensitivity, attributable primarily to its front wing, which runs in ground-effect. Its underwing is much less pitch-sensitive than that of an F1 car, due to its significantly smaller mandatory flat area. Overall, Penske's Nigel Bennett reckons that the IndyCar's pitch sensitivity is only a quarter, perhaps even a fifth that of the F1 car.

F1 cars and IndyCars are now fitted with rear tyres of similar width. Nevertheless, says Bennett, "On slow corners, an IndyCar lacks grip – it understeers in and oversteers out. Compared with a Formula 1 car, with its extra weight, it feels ponderous, according to drivers who have driven both types."

At high speed, the relative lack of pitch sensitivity makes the IndyCar easier to drive than the F1 car. "An IndyCar invites the driver to go quicker," according to Ayrton Senna, who drove a PC21 over the winter.

Joining Senna in the McLaren International team, Michael Andretti, the 1991 IndyCar Champion, told *Autoweek*: "In an IndyCar, you can go into a corner and the car will tell you if the front is not going to stick, or if the back isn't. In a Formula 1 car, though, it seems like you don't know unless you commit yourself..."

While adjusting to life as Andretti's replacement in the Newman Haas Lola over the winter, Nigel Mansell lost the back end in Turn 4 at Phoenix. Keeping his foot down, he managed to bring the car back from the brink. He reportedly told his engineers: "You could never have done that in a Formula 1 car – not even a Williams!"



INDIANAPOLIS MOTOR SPEEDWAY IS as close as the racecar engineer can hope to get to racing in a wind tunnel. Even in low-downforce Speedway trim, carrying the small wings demanded by the regulations, any IndyCar is capable of generating well in excess of 3000lbs downforce at top speed. That is the level of downforce required to sustain a speed in the region of 220-230mph through the four, slightly banked turns of the Brickyard.

The contemporary IndyCar laps the two-and-a-half historic miles absolutely flat-out. The main challenge for the chassis engineer is to generate the requisite amount of downforce for the minimum amount of drag. At Indianapolis, lap average speed is primarily determined by the top-end power of the engine and the drag of the car.

There was some argument over the disappointing performance of the PC21 at Indianapolis last year. Nigel Bennett dismisses the suggestion that the car might have been pulling excessive drag. "We were at a very early stage in the development of the 265B engine. We were concentrating on getting it to run 500 miles. Our speeds were no better than those of the 265A cars, because we had no more power than them. We were a long way down on the XB at that stage..."

In 1993, the Indianapolis aerodynamic package has to conform to the new regulations banning flush rims and underwing fins, plus a new maximum rear wing chord length of 12-inch. Bennett says that the effect of the new maximum chord is nil. Last year Lola opted for a 17-inch chord, Penske for a 13-inch chord. Penske investigations reveal that optimised SuperSpeedway wings from 12-inch to 17-inch chord share the same lift/drag curve.

The ban on flush rims inevitably adds a little drag, arguably more so than the ban on underbody fins. The underbody is the primary source of downforce on SuperSpeedways. However, the fins enhanced this at virtually nil drag penalty. The wings add approximately 20% downforce and, in this form, are very efficient.

Converting the 40% wind tunnel model of the 1992 Indianapolis PC21 to 1993 SuperSpeedway regulations cost 1.3% more drag for a given level of downforce. Nevertheless, the PC22 SuperSpeedway package is an improvement over the PC21 package. In particular, it benefits from the car's slimmer dorsum.

Penske's 1993 SuperSpeedway front and rear wings and underwing are all new. This is the first year that Penske has produced a dedicated SuperSpeedway underwing. It will be run with the regular raised nose but - subject to testing - the standard vortex generators ahead of the pods will be removed.

In terms of the overbody flow, aside from the dedicated front and rear wings, the flap at the rear of the deck and the height of the

cockpit air deflector will be altered.

In the light of wind tunnel testing, Bennett says, "The new Indianapolis package represents quite a lot of improvement over the 1992 package." That in turn represented significant improvement over the 1991 package.

Bennett quoted downforce of 3010lbs at 220mph for the PC20 at Indianapolis in 1991. He says that the lift figure to which he works has not changed by more than half a percent in five years. While the lift/drag ratio was quoted as 2.8 in 1991, Bennett will not be drawn to give a figure for the PC22. If the 1991 car was pulling 1075lbs drag, we suspect that the latest car sees less than 970lbs, giving it a lift/drag ratio better than 3:1.

In SuperSpeedway trim, the PC22's cooling intake remains unchanged, with the exit flap adjusted as appropriate to the ambient temperature. However, the brake cooling ducting is replaced, a plate over the upright intake orifice accommodating a NACA duct or a tiny scoop. These flows are ducted to the wheelbearings rather than the underemployed brakes. The NACA ducts are on the left-hand side, the scoops on the more heavily loaded right-hand side.

Bennett refuses to divulge the PC22 wheelbearing system: "It has been the subject of a huge research programme," he points out. On a SuperSpeedway, the sheer speed of wheel rotation, combined with the massive loading imparted by 4.5G cornering, puts a very high strain on the bearings. Danny Sullivan's PC19 hit the wall hard when a wheel bearing seized on lap 19 of the 1990 Indy 500. On a SuperSpeedway, Penske constantly monitors wheelbearing temperatures...

Hitco carbon-carbon discs and pads are employed, together with the regular Alcon calipers. A six-tooth replaces the regular nine-tooth steering pinion. No reverse gear is required and six forward speeds are deployed. Fifth and sixth are within a few miles per hour of each other to cater for changing wind and track conditions.

Typically an IndyCar runs a spool on a SuperSpeedway but Bennett refuses to confirm that the PC22 will be so equipped at Indianapolis this year.

In SuperSpeedway trim, the car will carry 30-40lbs of ballast. Bennett says that the PC22's static weight distribution might be modified from road racing trim, in the light of testing.

However, it is certain that, for high-speed stability, the centre of pressure will be behind the centre of gravity, whereas in road racing trim it can be ahead. As ever, the PC22's SuperSpeedway aerodynamic package provides for very precise location of the centre of pressure. Bennett emphasises this: "The aerodynamic balance of the car is super-important at Indy."

Happily, the fact that the front wing is kept relatively high off the track by the regu-

## "Neutral steer feels loose on a super-speedway"

lations reduces pitch sensitivity. Compared with its road course trim, the SuperSpeedway car is relatively insensitive to pitch, as it is to heave (equal change of ride height front and rear). In any case, lapping a SuperSpeedway the car is not subject to significant pitching or heaving, which helps to stabilise the centre of pressure.

In practice, there is the occasional deceleration to accommodate racing situations. And even at full throttle, there is considerable deceleration as the car enters each corner: its speed reduces by about 8mph. The design of the Indianapolis aerodynamic package is such that the centre of pressure can be made to move rearwards as the nose dips, generating a natural, safe aerodynamic understeer.

On a clear lap, typical wheel movement is no more than 0.4-inch at the rear, 0.15-inch at the front. The lack of wheel movement means that there is no real camber change and no relevance for progressive-rate springing.

In fact, the chassis is set up at a tilt so that the underwing will run flat on the banking. A combination of tyre stagger and asymmetric camber settings helps to steer the car into the banked turns. Typically, says Bennett, the camber is about +2deg on the left, and between -1.5deg and -3deg on the right. Wheel rates tend to be higher on the right-hand side - sometimes as high as 3000lbs/inch both front and rear. Tyre pressures also differ - typically 38/39psi on the left-hand side and 48/49psi on the right-hand side. In road racing trim, tyre pressures range from 15-30psi, according to the nature of the venue. The Speedway rear tyre is of smaller diameter than the road racing rear but the geometry of the suspension is unaffected, ride height adjustment compensating.

In regular SuperSpeedway running, a car should ideally have neutral steer, but the drivers like the comfort of some understeer, says Bennett. "Neutral steer feels loose," he explains.

## SuperSpeedway safety

The dry weight of an IndyCar is approximately 40% greater than that of a Grand Prix car. Much of the excess goes into chassis materials. Mindful of the speeds attained on the SuperSpeedways and the unforgiving nature of the brick walls that line them, the IndyCar regulations demand a much more substantial chassis structure than the Formula 1 regulations. Stripped of suspension brackets and rollhoop, the PC22's advanced composite monocoque and nosebox still weighs a hefty 120lbs.

Nevertheless, Bennett feels that the current weight limit is too high in view of the amount of ballast that the PC22 carries in Indy trim. He says: "With the latest engines, the limit could be 50lbs lower. Extra weight is extra energy to be dissipated in the event of an accident..."

## "The aerodynamic efficiency of the PC22 is 5% better"

► radiator core area. The cooler arrangement is new, with the cores now vertical but angled so that the cooling airflow can still exit the pod at the corner ahead of rear tyre, via a ramp. The flow rate is adjusted at the outlet rather than the intake.

Improved intake and exit ducting design has improved cooling efficiency - and has lessened the impact of the

cooling system upon the car's lift and drag performance. Overall, Bennett says that the PC22 represents a substantial improvement in aerodynamic efficiency over the PC21 - apparently, something in the region of 5%. In turn, the PC21 represented a similar advance over the PC20.

As standard, the PC22 rear wing has a main element, a thin leading edge slat

and two steeply rising trailing edge flaps, the upper of which carries a Gurney flap. Only the trailing edge flap angles are adjustable. A low-downforce version of the wing dispenses with the leading edge slat and is used at circuits such as Surfers Paradise, Long Beach and Elkhart Lake.

A so-called 'Cascade' alternative is rarely employed. This also dispenses



The PC22 has the same basic structural layout as the 1992 PC21 but moving the spring/damper units atop the scuttle permitted one bulkhead to be deleted. Both the monocoque and the nosebox have an aluminium honeycomb core and a mixture of carbonfibre and hybrid carbonfibre/Kevlar skins.

Penske makes only limited use of high-modulus carbonfibre, as favoured by Formula 1 teams for its potential for high torsional rigidity. "Given the minimum skin thickness requirements specified by the IndyCar regulations, even if the car was made of glassfibre it would be stiff enough," Bennett comments.

The drawback of high modulus carbonfibre is its brittleness. Likewise, Kevlar might not have the stiffness of carbonfibre but, in the event of impact, it offers much more progressive deformation. It is also lighter. One problem in using Kevlar is the difficulty of bonding, but Bennett says that Penske uses a resin system that does a very good job indeed. Penske's hybrid skins laminate carbonfibre-only plies with plies formed as a weave that combines carbonfibre with Kevlar.

In the interests of driver protection, the carbonfibre/Kevlar hybrid skin is employed wherever crashworthiness is more important than ultimate rigidity. Primarily this is in the nosebox and the flanks of the driver cell. There is a higher percentage of Kevlar in the nose than in the monocoque.

In the latter, new longitudinal beams help to protect the driver's legs against the danger of front wheel penetration. In addition, a solid Kevlar beam reinforces the rim of the cockpit aperture, its massive impact resistance again helping to guard against the danger of wheel penetration.

In the scuttle area, the support for the spring/damper units and their attendant rockers takes the form of a separate moulding which is bonded to the monocoque shell. The shell is complete without the moulding, the addition of which adds to strength in the longitudinal plane rather than to torsional rigidity. More importantly, using a separate moulding enabled Bennett to achieve a straighter scuttle line for the main shell.

This feature Bennett considers very significant in the light of Nelson Piquet's accident last year. He explains that the heavy impact saw the Lola chassis fail in the dash area.

"In a severe frontal impact, a straighter chassis line provides a better line of reaction back through the monocoque," Bennett reasons. He adds that the PC22's driver cell is designed so that there is an increase in material thickness from front to back. Bennett: "The cell should crush as a cone. We are looking for a progressive energy absorption, rather than a failure at the dash bulkhead before the area around the feet has crushed."

with the leading edge slat but it adds two more flaps behind the existing trailing edge flaps, making it a five-rather than four-element wing. The Cascade wing might be appropriate at Milwaukee (on the bumpy, unbanked, one-mile oval there), or on the undulating and sinuous road circuits of Mid-Ohio and Laguna Seca.

On the slightly banked, one-mile



oval at Phoenix, the average lap speed is in excess of 165mph. Faster than Milwaukee, Phoenix has a smooth, high-grip surface, on which a cornering force as high as 4.75G is sustained for no less than 8 seconds at a time. That is higher than at Indy, where 4.25-4.5G is the norm. Nevertheless, the car carries the standard road course aerodynamic package.

On a slow road circuit, such as Detroit, the same package is employed but the front wing tends to be worked harder: steeper flap angles and a higher Gurney have a detrimental effect on the cooling flows and hurt the flow to the rear wing. The lift/drag ratio suffers and the centre of pressure moves forward, ahead of the centre of gravity, causing an aerodynamic imbalance, which could not be tolerated at Phoenix. There is, however, a significant overall gain in downforce.

The faster the circuit, the more important is aerodynamic efficiency and the aerodynamic balance. Bennett says that IndyCar downforce in road race/short oval trim can be in excess of 3500lbs at 165mph, the maximum value being seen at Detroit. At the

**Front and rear suspension of the PC22. At the front (top) the dampers are now mounted over the scuttle while at the rear the wishbones are mounted higher.**

faster Surfers Paradise and Long Beach venues, the loading is "way under 3000lbs" at the same speed, Bennett admits. He says that PC22 downforce varies by 25% from the highest to the lowest road race/short oval configuration.

### Transaxle

The PC22 carries a development of the brand-new Penske transaxle introduced in 1991, which moved the gearbox ahead of the crownwheel & pinion. The gearbox incorporates three transverse shafts. The first transverse shaft takes the drive from the input shaft via a pair of bevel gears and, in turn, drives the two ratio shafts, each mounted higher and further back. This arrangement leaves the final drive (via a pair of spur gears) at the right height to avoid the universal joints working the driveshafts through an excessive angle.

The input bevels are produced by Xtrac, while the dog clutch engaged ratios and the steel shafts carrying them are a mixture of UK and US parts. Gearbox lubrication is described as "semi dry sump" and employs one pressure and one scavenge pump, ▶



► both driven off the input shaft. The final drive is through an undisclosed type of differential or a spool. Steel driveshafts are connected by ball-type constant velocity joints.

The aforementioned reshaping of the transaxle case has been permitted by a revised rear suspension layout. Previously the wishbones were as low as possible, the lower wishbone crossing the diffuser tunnel. This year, they are as high as possible, with the lower wishbone now shrouded and the upper wishbone above the tail cover.

The PC22 transaxle case is thinwall aluminium, rather than the more usual choice of magnesium. Bennett says that, by using aluminium, he can achieve a comparable weight for a given stiffness. "Magnesium tends to lose rigidity when hot. You can cast the walls thinner in aluminium, but there are inevitably some bosses, radii and so forth on which you cannot match the weight of magnesium. We are not really concerned with the ultimate lightness, so we choose the stronger material."

Developed in conjunction with Xtrac, the inboard gearbox was first equipped with a mechanical sequential change in testing last summer, and the system was raced at the final event. Xtrac has amassed a lot of experience of sequential mechanisms over the last few years, and the detail design of the PC22 system was by Penske Cars, with Xtrac's input.

Of course, a sequential system is usually the basis of an automated change. Although the 1993 IndyCar regulations ban that, Bennett reasons that a mechanical sequential change offers a number of advantages. "It's quicker and makes it virtually impossible to miss a shift," he says. "It demands less precision from the driver, who finds it easier just having to push or pull a lever. The only drawback is that he can't deliberately miss a gear, which can be a slight disadvantage on certain circuits."

Penske is currently evaluating the appropriate number of clutch plates, given the ban on carbon-carbon as the clutch friction material. Previous sintered metal clutches had 7.25-inch rather than 5.5-inch diameter plates.

### Brakes

The use of high Mu-value, carbon-based pads, such as Performance Friction Carbon Metallic and Hawk Carbotic, puts a lot of heat into a braking system. Penske's calipers are bespoke items designed in conjunction with Alcon. Bennett explains: "The team has a good, steady development programme, aimed at improving temperature control and caliper stiffness. We reckon that we now have the best brakes of any IndyCar team."

Brake cooling options include two sizes of road course scoop – "huge and

very huge!" For short ovals, however, there are no scoops, the upright instead carrying a plate with a NACA duct inset to collect air to cool the wheelbearings. A lightweight version of the Alcon cast-iron disc is employed, this having thinner plates. On the ovals, less use is made of the brakes and consequently there is less danger of disc distortion and cracking.

### On Track

In general, Bennett says, the aim is to run the car as low as possible, which implies running it stiff. That in turn reduces pitch and roll, to the advantage of aerodynamic performance. However, the tyres want the car softly sprung for maximum adhesion, so there has to be a compromise, he explains. Even on a smooth road course, the car will not have a ride height as low as it is physically possible to achieve.

Wheel rates on road courses are typically 700lbs at the rear and 1000-1200lbs at the front. Bennett will not be drawn on the question of progressive rate increases, other than to admit that, on some circuits, sophisticated bump rubbers provide a rising rate. Sometimes droop is eliminated at the front and the springs are pre-loaded.

Typical wheel movement is quoted as 1.0-inch at the front, 2.0-inch at the rear. Camber change is "average" according to Bennett, implying around 0.5deg/inch. He says that anti-dive and anti-squat are run only on certain circuits. These characteristics are achieved through alteration of wishbone pickup points, as are alternative front and rear roll centres.

Bennett tells us that, on IndyCars, the rear roll centre tends to be at or above the level of the chassis base, the front somewhat lower. However, he points out that, in the dynamic state, wide and somewhat flexible race tyres complicate the roll centre picture to the extent that even those centres theoretically fixed probably move in practice.

Front and rear roll centre locations affect weight transfer, as do the location of the centre of gravity and the wheelbase length. As we have noted, the PC22 has a lower centre of gravity and a longer wheelbase than its predecessors.

Although the car is designed with front and rear anti-roll bars, the bar at either end might be removed. For most tracks, however, both bars are retained. In general, a lot more roll stiffness is required for ovals than for road courses.

Penske Racing exploits dampers from sister company Penske Racing Shocks that are said to be a year ahead of those supplied to other IndyCar teams. In 1993, nevertheless, three-way adjustable units replace the four-way adjustables run in 1992. "They made life too complicated," Bennett concludes. ■

"I RECKON THAT, OVERALL, THE PENSKE PC22 is probably 15-20% better than the PC21, from my point of view. We've made some big improvements in the aerodynamics, we have more downforce and less drag, and, with the longer wheelbase, it is very stable. That's where the car really excels. It is very stable in fast sweepers and it is a real big improvement on a one-mile oval."

"I haven't driven it on a SuperSpeedway yet but I've tested on the Phoenix short oval. So far this year at Phoenix we've done very well with our times. We're not suffering any looseness or drastic understeer, it has just been a case of conditioning the car to the track conditions, so it seems to be very good. The added downforce with less drag really helps a lot and the car never seems to do anything awkward. I think we've got an excellent racecar."

"The PC22's mechanical grip seems to be very good. Aerodynamically we've gained a lot more grip and we've lost a lot of drag, which is what you want to achieve – but it's tough to get one without the other. Out of the box, the car has been very good. It's a development of last year's car and from the work we did last year we've been able to come out with near-perfect setups and be very fast. We just have to fine-tune the car."

"At this time I have raced it once, at Surfers Paradise. Although we had the chassis working really well there, the motor hadn't yet reached its true potential. We were getting bad throttle response off the turns."

"We were getting a big hit of power in the mid-range. We needed more power off the bottom end, from 6000rpm onward, whereas it seemed to come to life at around 9000 and wanted to spin the tyres. We were able to control that and accept the power, whereas the Lolas were struggling. They were spinning the rear tyres all the time and couldn't get off the turns. They just couldn't get the rear grip we had. We had a good handle on it and were able to get power to the ground, so that helped."

"Surfers Paradise has real tight corners leading onto long straightaways, so getting the power down is crucial to having straight-line speed. I was about 5mph faster than Nigel Mansell on the straightaway. I had the fastest car on the straightaway, so we're very confident about the power the Chevrolet C is making and the aerodynamics of the car."

"We just need to get the power delivery right. The engineers will fine-tune on the mapping and trumpet lengths and curve the power off the bottom a little bit better. I think we'll have an excellent package once we have the motor programme sorted out."

"With this car, the initial turn-in on the brakes is good. The PC22 turns very well, but when you get off the brakes the front seems to pick up a little bit. You have good grip as you turn in but, as soon as you get off the brakes, it tends to have a mid-turn understeer – when the car's in transition and the front's lifting back up. We've been working with the shocks to reduce the amount of lift."

"With the hard-compound tyres we have, it seems that you will always have some mid-turn understeer, so you're not getting the power down where you would like to. The optimum situation would be to be able to put your foot flat to the floor, and the car would accept all the power. With the PC22, power-down is much improved over last year's car, which helps. Last year we developed a traction control system that definitely helped us a lot. Since we can't use it this year, we concentrated in winter testing on getting the power to the ground and now we've got good traction."



# FROM THE COCKPIT PAUL TRACY

"Straightline stability is good and, under braking, the car is also very stable. Penske Racing has always been very conscious of brakes. We've done a lot of work and come to a pretty good setup. There's a lot of trick stuff around, triple-pot calipers and so on, but I don't think anyone can go any deeper than us.

"We never get fade or pad knock-off, other than the knock-off you sometimes get on SuperSpeedways because you're not using the brakes. You run without them for around for 30 laps going over 200mph through the turns, and the pads can get away from the discs. It takes a couple of pumps when you're coming into the pits to get the pads up against the discs again.

"They set up the brake balance on a machine when they're setting up the car, and then it's pretty much set, within a half-turn or a turn either way, front to rear. I only use the brake balance once in a while. Not very often. It really depends on the track. If the track's a little bit slippery and the brakes are locking, then I might.

"Ease of driving is improved this year and the steering effort seems to be a little lighter. That is one thing that we need to work on. On ovals, having a real light feel to the steering wheel means you can't feel what the car's doing. I think a little more caster could be a help, to try to get a heavier feel to the steering.

"Basically, you can set up the car any way you want for an oval, it all depends what feel you want from the car. If you want it to turn in very quick, you can have that. If you want to slow the steering down, you can do it. I prefer to have it a little in-between, not a real slow turn-in, and not a real quick one because then, if you have to get abrupt with the steering wheel due to traffic, you can find the rear end wanting to come out...

"On street courses, often we don't run a front or rear roll-bar but, on ovals, we use a lot of roll-bar adjustment. You pretty much go through the whole range. You start off full stiff, front and rear. I like to set up the car with a some understeer, so when I get into traffic I'm not going to be fighting to hold on to the car.

"If you've got a big understeer you can start working soft on the front bar. Usually about three-quarters of the way through your tank run, you get to the point where you are starting to go into a bit of a loose situation. Since you are soft on the front bar by then, you can start working back stiffer on the front bar to get the understeer back into the car.

"Then, over the course of the next 10 or 15 laps, if it starts to go loose again you've got the full adjustment of the rear bar. You can go softer on the rear bar to get more grip on the rear.

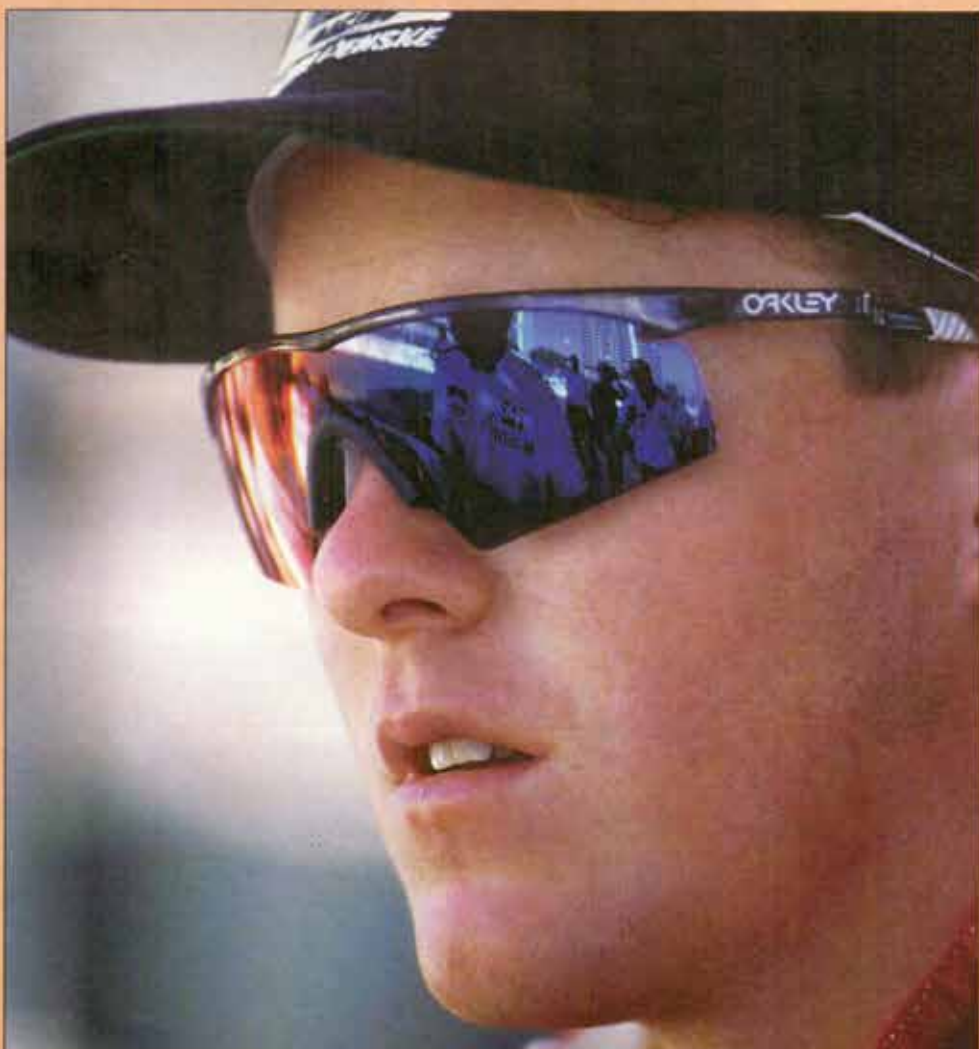
"We try alternative springs in qualifying. We start with a baseline setting and it usually only varies within a couple hundred pounds either way, track to track. It's not an overly stiff setup that we use on the PC22 so the ride is not very harsh. Compared with the PC21, we seem to have smoothed out the ride control with the newer shocks that we have.

"We do quite a lot of damping changes. I'm not a damping expert and the latest shocks are so technical, there are so many adjustments, I just try to tell the engineers what I'm feeling.

"The PC22 is really responsive to wing adjustments. Rear wing adjustments are drastic, front wing adjustments on the flap are not. They are not drastic in that they don't slow down the car in straightline speed, but they are very effective in helping the turn-in.

"We don't really play with the ride height.

**"We've been able to come out with near perfect setups and be very fast... I think we've got an excellent racecar."**



If you were going to pile a bunch of front wing or rear wing onto the car you would have to adjust the ride height. There can be a time when you need some extra downforce in qualifying, then you're not going to change the ride height. But, for a race, you're going to have to raise it a little so as not to ruin the bottom of the chassis.

"We don't really play with differential settings. We generally put a spool on the car for an oval which walks the rear end, and pretty much we run a limited-slip on road courses...

"Tyre pressures don't vary much. Sometimes we run a couple of pounds either way, nothing drastic. One thing that seems to be very good about this car is the tyre wear...

"On the PC22 we have the sequential gearchange, which is very good. You can change gear in one-third of the time it takes to put your foot on and off the gas, so it is quick. I've been working with the sequential system since halfway through last year, just ironing out the bugs. It seems to be that, when everything's going right, it's magic. But we're still in the development process, we've had some problems on testing and we're working on it...

"This car is comfortable. It's fairly roomy compared with some of the other cars around, it's not real cramped, you have a lot of legroom and the seat is very comfortable. For instrumentation, we have the Pi dashboard display on which you can put pretty much anything you want. We generally run the basics - water temperature, oil temperature, boost pressure and tachometer - but we can also have fuel mileage, an indicator for which gear you're in, a speedometer - pretty much anything you want on it, they have sensors all over the car."







## LOLA T93/01: SPECIFICATION

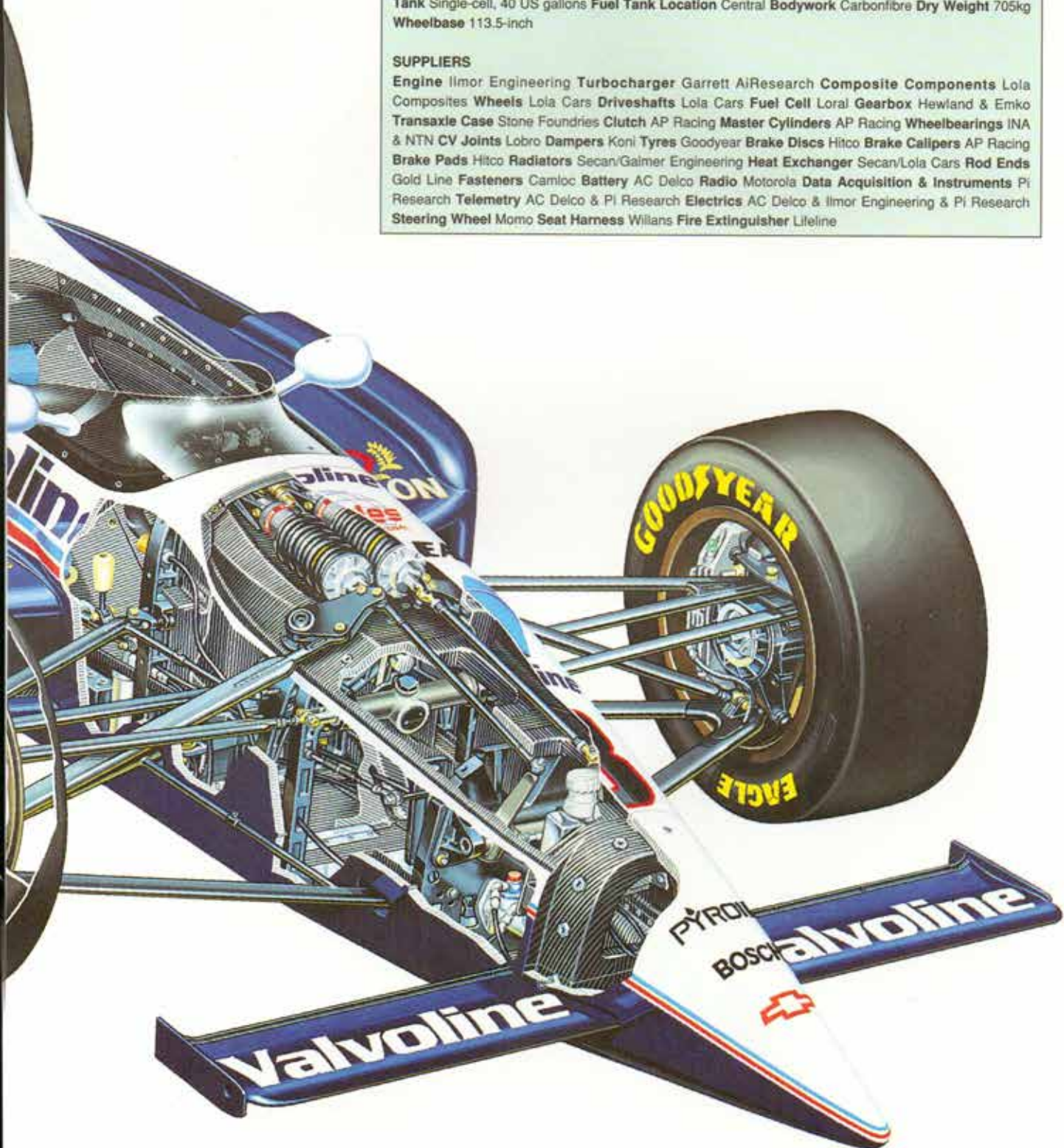
Marque Lola Model Designation T93/01 (Galles) Producer Lola Cars Specification Date May 1993

### COMPONENTS

**Chassis** Carbonfibre monocoque **Engine** Chevrolet Ilmor V8, fully stressed **Transaxle Case** Aluminium alloy with outboard longitudinal gearbox **Gearbox** Six-speed (no reverse), non-synchro **Clutch** Sintered 5.5-inch triple-plate **Differential** None (spool) **Driveshaft** Steel with CV joints **Front Suspension** Pushrod **Rear Suspension** Pushrod **Dampers** Oil **Wheels** Magnesium one-piece 15-inch diameter **Brake Discs** Carbon-carbon, outboard **Brake Calipers** Single, six-pot **Water Coolers** Two, pod-mounted radiators **Engine Oil Coolers** One, heat exchanger **Oil Tank Location** Fuel tank area **Fuel Tank** Single-cell, 40 US gallons **Fuel Tank Location** Central **Bodywork** Carbonfibre **Dry Weight** 705kg **Wheelbase** 113.5-inch

### SUPPLIERS

**Engine** Ilmor Engineering **Turbocharger** Garrett AiResearch **Composite Components** Lola Composites **Wheels** Lola Cars **Driveshafts** Lola Cars **Fuel Cell** Loral **Gearbox** Hewland & Emko **Transaxle Case** Stone Foundries **Clutch** AP Racing **Master Cylinders** AP Racing **Wheelbearings** INA & NTN **CV Joints** Lobro **Dampers** Koni **Tyres** Goodyear **Brake Discs** Hitco **Brake Calipers** AP Racing **Brake Pads** Hitco **Radiators** Secan/Galmer Engineering **Heat Exchanger** Secan/Lola Cars **Rod Ends** Gold Line **Fasteners** Camloc **Battery** AC Delco **Radio** Motorola **Data Acquisition & Instruments** Pi Research **Telemetry** AC Delco & Pi Research **Electrics** AC Delco & Ilmor Engineering & Pi Research **Steering Wheel** Momo **Seat Harness** Willans **Fire Extinguisher** Lifeline







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**T**he Lola T93/01 is the Super-speedway version of the Lola T93/07 Chevrolet C engine IndyCar, intended specifically for use on the 2.5-mile Indianapolis Motor Speedway, with its four lightly banked, high-speed turns.

Seven such cars qualified for the 1993 Indy 500, including the example depicted overleaf by Tony Matthews's outstanding cutaway, which was entered by Galles Racing International for Al Unser Jr.

Galles had two more cars in the race, for Danny Sullivan and Kevin Cogan. Budweiser King Racing also had three such cars, for Jim Crawford, Roberto Guerrero and Al Unser Sr, and the last was the Hall/VDS Racing entry for Teo Fabi.

The purpose-designed Chevrolet V8 IndyCar V8 race engine is produced by Ilmor Engineering. Ilmor made its first such engine in 1986 and soon put Chevrolet in the forefront of IndyCar racing. Last year Ford responded with the brand new Cosworth XB engine, smaller and lighter than the Ilmor Chevrolet and more powerful. New for 1993, the C-version of the Chevrolet is Ilmor's response to the Cosworth. It has an 80deg rather than 90deg bank angle, and is notably smaller than its predecessors. Measuring 22-inch long, 22-inch wide and 22.8-inch high, it is comparable in size to the Cosworth Ford XB (introduced in 1992), to the advantage of over-car airflow.

Last year, the Lola-Chevrolet teams had to suffer an inferior aerodynamic package compared with Lola-Ford Cosworth XB runners. That disadvantage has now been eliminated.

Compared with the T93/07 road racecar, the 1993 Superspeedway package features a longer wheelbase and a bespoke (lower drag and lower downforce) aerodynamic package, including alternative front and rear wings to conform with USAC regulations for the 500. It also features alternative sidepods, with a reshaped air inlet and a side (rather than a top) air exit.

Galles did not employ T93/01 sidepods, retaining T93/07 issue. The team followed its own aerodynamic development path which incorporated scale-model, moving ground plane wind tunnel testing. Galles devised its own Speedway underwing and relocated the T93/01 rear wing, mounting it higher than standard and fitting deeper end-

plates Galles also had its own ideas on weight distribution which, as standard, is modified with the switch from T93/07 to T93/01 specification. The T93/01 requires a significant amount of ballast to bring it up to the mandatory minimum weight of 705kg, part of which is supplied by a stainless steel (rather than aluminium) skidplate.

At 113.5-inch, the wheelbase of the T93/01 is 2.0-inch longer than that of the T93/07, the extra length being achieved by means of alternative front suspension linkages, which also offer different geometry. Galles retained the T93/01 front suspension but employed its own rear suspension with alternative geometry.

The T93/01 has pushrod front and rear suspension with twin coil-over-damper units, mounted at the front on the scuttle, at the rear on the transaxle case. Unusually, to help keep the rear shroud as small as possible, the rear dampers are mounted behind their attendant pushrod rockers, and consequently a double-rocker system is employed.

Fabricated steel uprights carry a combination of taper roller and ball bearings. The upright is carried over from the T93/07, retaining standard wheelbearing and brake cooling air orifices, but these orifices are not fed by scoops. Neither does air centrifuge through the brake discs — stopped by AP Racing six-pot calipers, the T93/01 is equipped with solid carbon-carbon discs, which are hardly used, other than for calling at the pits.

In 1993, flush rims are illegal, and a crossflow through the spoked Lola Cars one-piece magnesium rim helps to keep the wheel bearings cool. At the rear, low pressure under the car draws air in through the wheels. At the front, the blockage caused by the pod forces air out through the wheels.

The rear wheels are driven through Lola/Lobro CV joints by steel drive-shafts. Instead of a differential, the T93/01 employs a spool — a solid link between the driveshafts.

Rather than having a transverse gearbox located ahead of the final drive (in Formula 1 fashion), the T93/01 has a longitudinal gearbox mounted outboard, in traditional style. This is fed through a step-up gear from an AP triple-plate sintered metal clutch of 5.5-inch diameter.

The dry-sump gearbox is a Lola Cars design and carries mainly Hewland-manufactured internals. Galles

employed Emco gears for the 500. The T93/01 has an aluminium transaxle case which forms its bellhousing, as well as its final drive housing and gearbox main case. This casting has essentially the same external shape as the case that was designed for the XB car last year.

The T93/01's monocoque and structural nose gives form to its central fuselage. These items are produced by Lola Composites in carbonfibre-over-aluminium honeycomb. The monocoque is made in a female mould as separate upper and lower sections, which are bonded together after the insertion of internal bulkheads. The portion of the lower section between the dash and seat back bulkheads is skinned in aluminium, rather than carbonfibre, in order better to protect the driver's hips and thighs against the danger of penetration.

Both the (integral) front and the (bonded-in) seat back bulkheads are carbonfibre whereas the pedal bulkhead, the two semi-bulkheads supporting the front suspension and the dash bulkhead are aluminium alloy productions, as is the bolted-in rear bulkhead. Removal of the rear bulkhead gives access to a 40 US gallon fuel cell. The oil tank is located in the fuel tank compartment.

The Lola bodywork (front damper cover, sidepods and engine cover) is carbonfibre-over-honeycomb of aluminium or, in some areas, Nomex. The wings and underwings are carbonfibre over an aluminium core. The front wings locate on a steel cross tube through the nose, while the rear wing is carried on aluminium pillars which attach to the transaxle case.

The sidepods contain water radiators which service both the engine coolant and a twin-core oil:water heat exchanger for engine and transmission lubricants. The only other cooling intake is a NACA duct on the engine cover which feeds cool air to the centre of the engine's vee.

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## AL UNSER JNR'S INDIANAPOLIS 500 TITLE DEFENCE

We had all been waiting for this: a head-to-head clash of the Titans. In one corner: Ford Motor Co, with the Cosworth XB engine which, in 1992, had rendered the rival Ilmor redundant. In the other corner: General Motors, with Ilmor's new, competitive Chevrolet C. Crack teams represented both companies: there was no obvious pre-race favourite for the 1993 Indianapolis 500. The Galles team equipped Al Unser Jnr with a modified Lola-Chevrolet C but, in practice, the Cosworth was seen to have an edge over the newer Ilmor. Fifth on the grid, Unser's modified Lola was the fastest Chevrolet qualifier, and it finished the race less than 10 seconds behind the winner. Trouble was, between the victorious Penske-Chevrolet and Unser's Lola-Chevrolet, there were a half-dozen Lola-Fords. Galles and Unser came

downforce, albeit at something of a drag penalty.

Although there was a lot of talk in Gasoline Alley of "less downforce" this year, Brown emphasises that Junior had as much as he had enjoyed in 1992. Nevertheless, he found himself lifting for the turns this May, and therefore the quest was to add downforce in the most efficient way until the turns were flat. "But we never quite achieved that," Brown reports.

Junior elaborates: "On a qualifying run, full throttle all the way is the objective, but this year we didn't attain it. When I set my grid time, I did take Turns 2 and 4 flat (at the end of the short chutes), but not Turns 1 and 3 (at the end of the long straightaways). I didn't manage to take Turns 1 or 3 flat at all this year." Shaded only by the Lola-Ford of poleman Arie Luyendyk, Unser's best single lap in qualifying was run at 222.063mph. His trap speeds on that lap were 231mph (4mph slower than Luyendyk) at the start/finish, 230mph in Turn 1, 216mph in Turn 2, 230mph in Turn 3 (joint fastest of the month, with Luyendyk), and 218mph in Turn 4.

Brown admits: "Having got all the downforce back following the regulation changes, I didn't expect a problem of this nature. We found that, as we added downforce, the lap speed increased. Usually we spend all week prior to qualifying taking downforce off the car."

There were a number of reasons for this change — for this new Indianapolis challenge. Primarily, the new Chevrolet engine, and the changes to the Brickyard itself.

In spite of an increased level of drag, the greater horsepower of the Chevrolet C engine pushed up Junior's straightaway speeds by around 5mph. Reducing turn speeds to the level of 1992 implied a slight lift of the throttle on corner entry.

Whereas, in years past, Speedway cars had enjoyed negative lift in abundance, now they turned out to be light on downforce. Consequently, it proved difficult (indeed, impossible for Turns 1 and 3) to generate sufficient grip to maintain a higher corner speed, without an unacceptably high drag penalty.

Not only had increased engine power altered the very nature of the machine, but the track itself was also different. This year, it offered less grip.

In 1992, Junior had set his qualifying time staying above the white line,

# SO NEAR AND YET SO FAR

**T**he Brickyard issued a whole new challenge this year for defending Indy 500 Champion Al Unser Jnr, his engineer Alan Mertens, Galles Racing International team aerodynamicist Andy Brown, team owner Rick Galles and his entire Indianapolis crew.

Over the winter, the Galles team had switched back from its own, 1992 Indy-winning Galmer chassis to a Lola customer car, and Ilmor Engineering had developed a more powerful version of the "Chevrolet Indy V8". Meantime, USAC had changed the Indy chassis regulations, and the Indianapolis Motor Speedway had modified its famous 2.5-mile, ultra-high-speed oval — "The Greatest Race Course in the World".

In 1992, with his Galmer G92-Chevrolet A, 'Junior' had been able to lap the entire course flat-out, running a speed in the region of 230mph on the straightaways, which was scrubbed by about 15mph as the car took the 9deg

By IAN BAMSEY

banked turns. On a clear lap, Junior did not need to lift at all. Within its speed band of 215-230mph, the Galmer generated in the region of 3000lb of downforce. As usual, to improve Junior's lap times, drag had been minimised by backing off the downforce until the car was just — just — capable of lapping the track flat-out.

"In 1992 the turns were flat and we trimmed out the downforce to reduce drag," Brown confirms. "Downforce came off until the car became unstable — we might have thrown away 50lb downforce to save 15lb of drag. At 230mph, that 15lb of drag is worth approximately 1.5mph."

On the face of it, the 1993 USAC chassis regulations had cut downforce by 20-25% for a given level of drag, primarily due to the loss of underwing fences. Of course, racecar development never stands still. In developing a bespoke aerodynamic package for the Galles Lola T93/01 (see panel), Brown had been able to claw back the lost

Galles Lola-Chevrolet driver Al Unser Jnr gave his best shot to a second successive Indy 500 victory, but finished almost 10 seconds behind the winner. In eighth place...



## DRIVING THE GALLES LOLA AT INDY

► whereas many rivals dipped below: there had been a number of possible 'grooves'. This year, thanks to rumble strips replacing the white line (see page 46), there was effectively only a single groove. Very quickly, that groove got 'dirty', and offered less adhesion.

If Junior found he had to lift slightly entering Turns 1 and 3, so did all his rivals. In qualifying, the defending champion proved that he had the fastest Chevrolet car. Clearly, it enjoyed a very effective aerodynamic package.

Once the team had dialled in higher downforce, the maximum lateral G-force that was generally attained, according to the data logging, was marginally higher than seen by the Galmer G92 in 1992 — in the region of 3.3 G, which was sustained for 3 or 4 seconds.

The chief characteristics of Brown's aerodynamic package (see panel) were its vortex generators, its bespoke underwing, its higher rear wing and — a late addition — its T93/07 ('road racing') sidepods.

On the Tuesday after qualifying, the team tried a nose splitter to guide air to the tunnels. "Its use was inconclusive," says Brown. "And USAC would not have been happy with it, because it had not been fitted for qualifying."

Meanwhile, the Galles vortex generators had been copied by many other Lola users, while Mertens asserts that, "The raised rear wing was copied by Newman Haas — after qualifying!"

Strictly speaking, cars should race

in precisely the trim in which they qualified. But Brown asserts that Newman Haas raised the T93/01 wing section within the standard endplates, to stay within regulation dimensions. USAC did not object.

Galles remained the only Lola team to run T93/07 pods. Brown favoured their top exit over the side exit of Lola's intended Superspeedway pods: "The side exit throws air at the rear wheels, increasing rear wheel drag. I noticed that those cars running side exits were all adding bigger fences."

Galles did not use its road racing sidepods early in the first week. "The idea was too easy to copy," Brown explains. "We put them on late in the day. I knew from my tunnel research how to rebalance the car — our rivals wouldn't have had that information."

Cooling was a race day strength of the Galles T93/01 package, according to Mertens: "That might have been an advantage, but the others were saved by the weather!"

If the Galles T93/01 was the most effective Chevrolet car in qualifying, it was no match for the fastest Fords. "Even with the C-engine, we were down on power compared to the Ford," reflected Mertens. "Last year, the Cosworth XB was very strong straight out of the box, and also very economical. With the Chevrolet C, it took some time to get the response and the fuel economy right. Here at Indy, we were still lacking power. We didn't realise ►

"I'M DOWN ON HORSEPOWER... THE Cosworth XB is the strongest engine out there. And I reckon the Penske is the best chassis — mechanically it does work very well. Even here at Indianapolis, the Penske-Chevrolet is a good racecar, but the Ford Cosworth pulls the Lola away from it. Around this place, it comes down to horsepower..."

"In terms of aerodynamics — drag and downforce — I'm about equal with the other Lolas. I think I have a better racecar than the others because of the people who are engineering it, and also the mechanics working on it. Our team prepares a better Lola-Chevy than any other — and we prepare a better Lola than most. On turn speeds, I'm equal with all the Lolas out there. But, on the straightaways, those Fords accelerate very, very well..."

"The Lola is a good racecar. It's repeating its setups, maintaining its crossweights. It turns really well. But that's more important on a road course than here at Indy..."

"You do hardly any steering at all around here. It's pretty much a case of relaxing on the wheel on entry. Then you let it have its head on exit. This place is very different from a road course, and you can't even begin to compare a Speedway car with a road race car. You barely turn in and then, when you come back out, believe me, any sudden movement of the wheel means you lose control of the car. It's that simple."

"At Indy, you need a good back end, and you need to be able to steer the car into the corner. There's no correction once you've turned in. If you correct these cars at all, you're in deep shit..."

"What is the difference between running 210mph and 220mph? Nothing! The difference between taking it easy and running a





hot lap is the amount you lift for the turns.

"When I lift, I turn in and lift right at the entry. I go to about 70% throttle. I go from 100% to 70% and back up in less than a second. It's hardly a lift at all. It just helps the car to turn in.

"You don't lift more in the race than in qualifying, unless there's a car in front of you. If there's a clean racetrack on race day, you drive the car just like you did in qualifying...

"We're in top gear throughout qualifying and the race, so we only shift gear when we're leaving the pits. The Galmer shifted a lot better than the Lola — it shifted better than any racecar I've ever driven.

"We might use the brakes occasionally, when there's a lot of traffic, but we certainly don't use the brakes enough to have any kind of problem with them.

"The Galmer had slightly heavier steering than this Lola: the Lola before the Galmer had real heavy steering, and we had to make pieces to make it lighter. With the T93/01, the chassis response is pretty quick — but the engine response isn't very good at all!

"The Chevy A had a lot better response than the Chevy C — this engine doesn't accelerate like the Ford. At Indy, we tend to work in the band of 12,000-12,500rpm. The revs drop not only when you lift, but also due to the drag on the car in each turn. That also slows the car, unless it's really free — but if it's that free, I don't like driving it, because the back is so nervous.

"If the car is working well, then stability is good. But if you don't have a car working well here, stability sucks...

"The ride is much better once you get up to speed — it smoothes itself out, compared with, say, a warmup lap.

"The tyres are great. Goodyear has done a very good job. You can heat up the right rear, say, and then cool it down again, and then get it back up to speed. It can go off so bad you think you have a flat, but then you can slow down and cool it again...

"We have Pi instrumentation — it's the same dash I've been using for three or four years. There's a tach, there's a boost gauge, there's a fuel mileage gauge, there's oil temp and water temp. There's an alarm system. I look at the temperatures first. If they're running cool enough, then I quit looking at them unless an alarm goes off. Fuel mileage and boost are the things I look at. The tach is your speedometer. We can have an actual speedometer, but we rarely use it.

"Our pits-to-car radio works pretty well. We do talk about the car during the race, mainly about what changes we want to make at the next stop. The car has telemetry showing the guys back at the pits what fuel numbers it is actually turning, so the pits might radio me to lean off the mixture.

"The T93/01 cockpit is narrow. It wears down your elbows! But it doesn't cause any real discomfort and, if you want to go fast, you have to have it narrow...

"This car has been very responsive to changes. We helped it on the morning of qualifying by changing the springs. That really brought it around. We made a couple more changes, then went out and qualified. Even for qualifying, you have got to make yourself comfortable, give yourself confidence... A car has got to be comfortable to run 220mph. I didn't have to try making it more comfortable with the race setup: the guys who change their car for race day are screwed up.

"At the Speedway, the wind does affect the car, and it all depends which way it's blowing. East-west bothers the cars more

# FROM THE COCKPIT AL UNSER JNR

than north-south.

"An east-west wind blows across the straightaways and moves you back and forth across the track. That keeps you on your toes!

"A north-south wind affects the entries to Turns 1 and 3. If the wind is coming out of the south, Turn 1 gives you a pretty good turn-in, but not as quick as with the southerly wind going into Turn 3.

"A tailwind will make the car turn-in quicker than a headwind. The grandstands knock out the front wings when you're coming down the main straightaway — the tailwind has got the whole straightaway to really get onto you. A wind coming out of the south won't bother you so much in Turn 1, but it will make you a little loose coming off Turn 2 and going into Turn 3."

**"You barely turn in and then, when you come back out, believe me, any sudden movement of the wheel means you lose control of the car. It's that simple."**





GALLES RACING INTERNATIONAL TOOK delivery of its first Lola T93/07 chassis in mid-February, direct from the factory rather than via Galmer Engineering. Galmer is the UK-based R&D and manufacturing arm of the team, which supplies aerodynamic and other research services, and produces bespoke parts for the cars. In 1992, Galmer Engineering had produced the team's own chassis, the G92. Galmer is owned 50-50 by team owner Flick Galles and his team's technical director, Alan Mertens.

In past years, Lola Cars had been able to supply its latest model much earlier, enabling Galmer to carry out various tests in the workshop, then the Galles race team to undertake an extensive track testing programme. This year, there was precious little time for track testing prior to the shipment of the cars to Australia for the Surfers Paradise race in mid-March.

Seven weeks after Surfers Paradise, the Indianapolis Motor Speedway opened for the first day of practice for the 77th Indianapolis 500. Two more races had been run in the interim, and Galles had been able to incorporate its own parts into the Lola chassis, albeit without having been able thoroughly to test the model in its standard (baseline) guise.

Mertens reflected: "Ed Nathman had come in as team manager from Newman Haas with some

ideas and, as soon as I had seen the design, there were some other areas that I knew I wanted to change. We actually started drawing our own parts before we took delivery of the first chassis."

Aerodynamicist Andy Brown added: "Arriving on 5 February, our scale model of the car was almost as late from Lola as the car itself. That hurt our Superspeedway aerodynamic development programme. We had received a general arrangement drawing before the model, which had allowed us to produce some pieces to test, but we didn't start running in the tunnel until early March, just after the first track test."

Come 8 May 1993, Galles had five chassis at the Speedway to its own specification. It was running three cars for Al Unser Jr, Danny Sullivan and Kevin Cogan. The team was 28-strong with Galles, Mertens, Brown, Nathman, additional race engineer Dave Benbow, data loggers Greg Howland and Frank Hatten, a crew chief for each car, and a total of seven mechanics.

Mertens acted as the race engineer on Unser's car, Nathman on Sullivan's, and Benbow on Cogan's. The respective crew chiefs were Owen Snyder, Paul 'Ziggy' Harcus and Cole Selva.

On Pole Day, Arie Luyendyk's Lola-Ford took the glory at 226.182mph. Junior was the fastest Chevrolet runner at 221.773 for fifth on the grid, trailing the Lola-Fords of Mario Andretti, Raul

Boesel and Scott Goodyear. Sullivan was 12th on the grid at 219.428, Cogan 14th at 217.230. As it transpired, Cogan was actually the slowest qualifier overall — and was lucky not to be bumped from the race by the reigning CART IndyCar Champion, Bobby Rahal, a shock non-qualifier.

The start of the race found most cars running 'loose' due to the condition of the track. One of the worst off was Jim Crawford, who brought out the first yellow after 15 laps when he shunted his Lola-Chevrolet, caught out by snap oversteer. Junior was the best-placed Galles driver, running in the top 10 but not looking very strong, his car too loose for comfort.

Junior and Sullivan stopped under Crawford's yellow, unlike Cogan, who went on to lead four laps prior to the second yellow, which occurred after 30 laps. It was caused by a crash — by Sullivan. Strangely, Danny had found himself fighting understeer rather than oversteer — he understeered into the wall at Turn 3. A lightly loaded right-hand wishbone bolt held in double shear was found to be broken; the team suspects this was a legacy of the impact.

Cogan made his first stop during Sullivan's yellow. As the race settled down, Junior maintained station in the top 10, while Cogan faded.

A yellow at half-distance gave way to green on lap 102, with Andretti being chased by Junior, who had gradually dialled the oversteer out of his car. However, Junior found he could not keep pace with Mario, falling half a lap behind over 20 laps of green, if not losing his place.

As Andretti headed for the pits for a scheduled stop, another yellow left him with a controversial stop-and-go penalty. This USAC imposed while the race was still under the yellow! At the restart on lap 138, Junior consequently found himself leading from Andretti. After 15 laps of green, Andretti retook the lead. Emerson Fittipaldi's Penske-Chevrolet then closed on the Galles Lola — but could not pass.

On lap 164, however, Junior stopped: too early to run to the finish (on lap 200). At this point, there were still 10 cars on the lead lap.

It was another 10 laps before the next yellow. That gave Junior a chance to stop for a final splash of fuel, but it dropped him to the rear of the queue when the race went green.

There were, in fact, two more restarts, but Junior had fallen too far back in the line. Passing was more difficult this year, and Junior's final set of tyres left him with a big 'push'. He finished eighth. Cogan finished 14th, two laps down having found his car uncomfortable in traffic.



► the extent of the problem until we arrived. It was almost as though Cosworth could get more boost for qualifying..."

On Pole Day, certainly, the XB had a definite edge. Junior: "I found I could outrun an ill-handling Lola-Ford but, if they were handling any way as well as I was, they could get from point A to point B quicker. Our RPM could be the same to start with, the top speed we reach could be the same, but their acceleration would be better..."

In fact, the Lola-Fords tended to run 3-4mph quicker on the straights than the Lola-Chevrolts — suggesting a higher top-end power figure as well as more area under the relevant portion of the power curve.

"The Fords could pull more wing," Mertens observes. "Although people think we had a relatively high down-force solution with the road racing

**Apart from the Al Unser Jr entry, Galles Racing ran two more Chevrolet C engine Lolas for Danny Sullivan (top) and Kevin Cogan.**

sidepods, I don't think we were pulling more drag than rival Lolas. I think we were slower than the Fords on the straight due to the difference between the engines."

On race day, Junior found that the Fords could still out-accelerate him off the turns, although the power advantage was less pronounced. Junior simply couldn't get close enough to pass a Ford at the next corner. In clean air, he found he could keep Mario Andretti's Lola-Ford behind him but, once caught in traffic, the Newman-Haas car had the upper hand.

In contrast, Junior found he could hold off Emerson Fittipaldi's Penske-Chevrolet in a similar situation. That car, of course, came through to win.

The Galles team's Chevrolet C engines are prepared by Mike Wolther at VDS. Wolther runs the team's engine telemetry at races and assists with fuel

strategy. "This year we had less engine problems than in previous years when we ran the Chevrolet A," Mertens observed. "We had just a couple of bottom-end failures, one after just three laps the first day, the other towards the end of the first week. Remember, the C is a brand new engine. Other teams had similar failures. Ilmor replaced the units free of charge and was able to overcome the problem."

Mertens has nothing but praise for the service provided by Ilmor Engineering: "They had a huge truck here and an army of personnel. If we had any problem, they were over us like a rash. They could never do too much for us!"

Ilmor is part-owned by Roger Penske and, last year, Penske Racing had exclusive use of the B-version of the Chevrolet Indy V8. This year, the Penske, Galles, Hall/VDS, Rahal/Hogan,



Bernstein and Bettenhausen teams all have access to the C-version. However, some observers have pointed to the fact that Penske rebuilds its own engines, and suggested that it might quietly be enjoying more advanced Ilmor development than its rivals. Mertens doubts that: "The performance of Penske's car might suggest that it has a better Chevrolet engine. But I think that the PC22 chassis is better than the Lola chassis, so the whole car package works better."

Mertens reckons that the key to the Penske edge is a mechanical (rather than aerodynamic) performance advantage. The PC22 is reckoned to enjoy superior mechanical grip and enhanced handling balance. "This year, with the revised track, chassis balance is more sensitive than ever to climatic conditions," Mertens observed after qualifying.

Unser remarked — prophetically: "The air is so strong here, it makes up for any lack of mechanical grip. But when the track gets a lot of rubber on it, it gets very slick. Because of that, I think the Penske will come out in the second half of the race..."

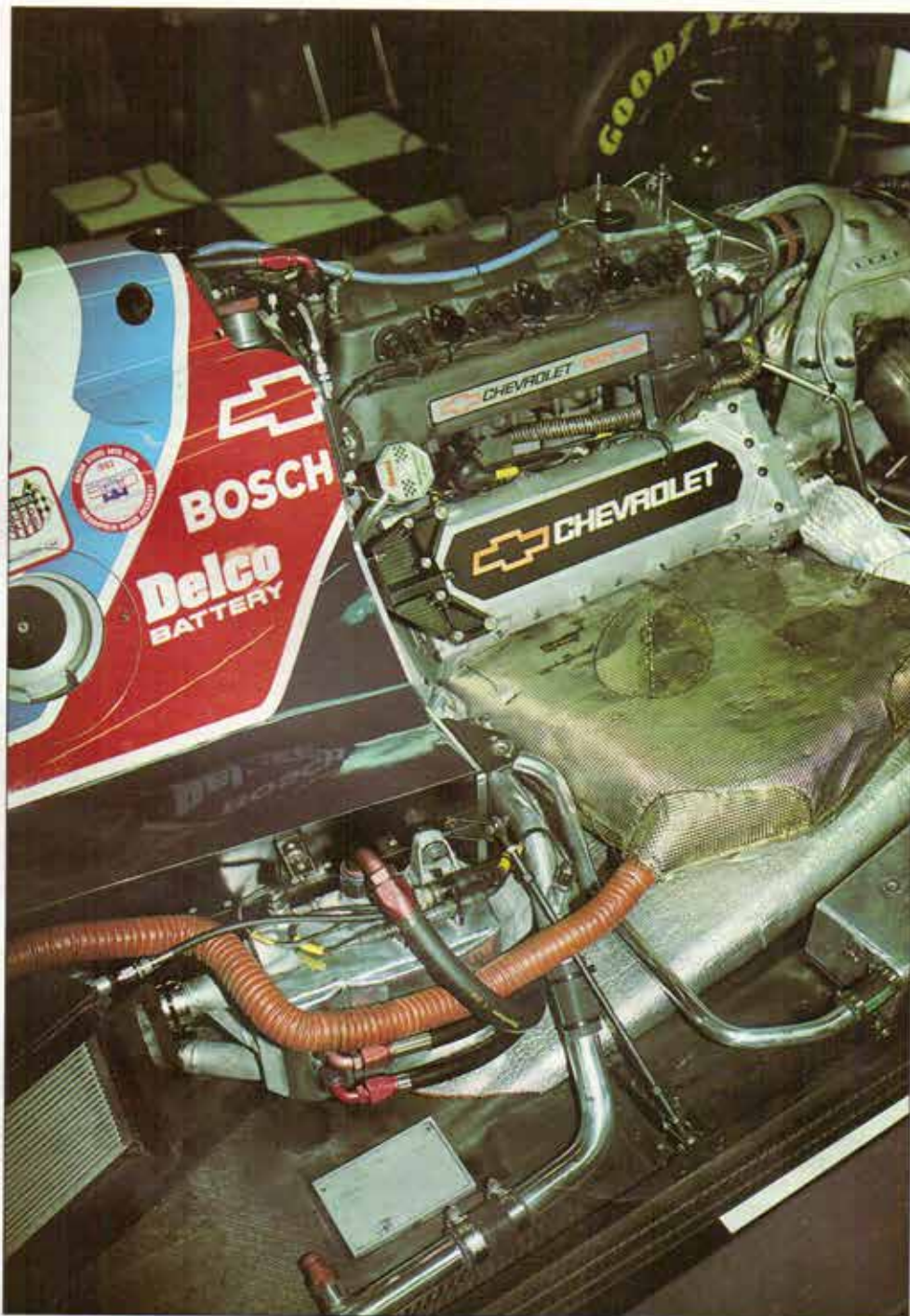
Logically, the significance of mechanical grip is less pronounced at Indianapolis than on a road course or a 1-mile oval. Nevertheless, chassis balance is a major consideration — the car must give the driver confidence if he is to exploit its potential to the full. Mertens explains: "Our downforce gives us the grip we need, but the mechanical setup gives us the balance that the driver needs to control the car through the turn."

Junior adds: "The air package dominates these cars at Indianapolis. If your turn on exit is too quick, you change your wings a little, or the rake a little, and that cures the problem — you don't jump to springs or shocks or roll-bars, that sort of thing. But all that does matter once you get into the corner and everything starts to react mechanically."

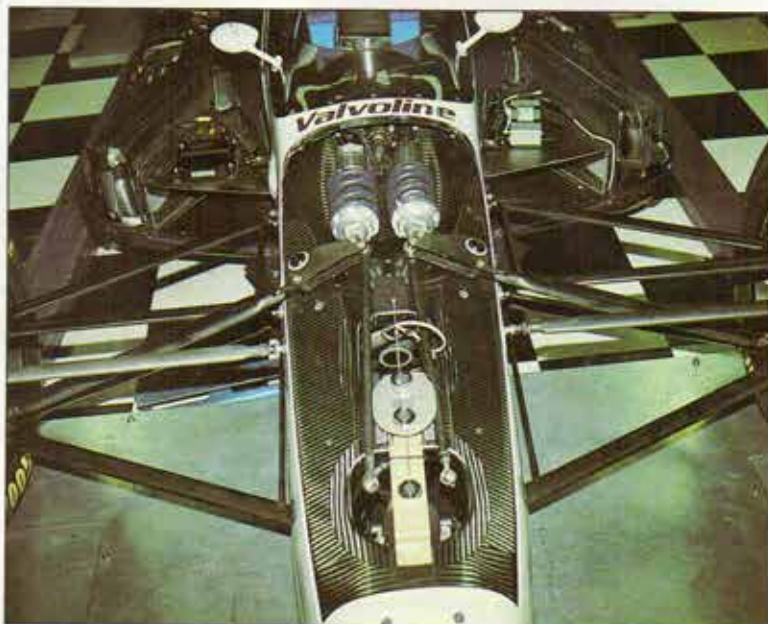
Junior had found that his biggest challenge throughout May 1993 was to get the Lola to turn-in: "We did have a problem with trying to get it to turn. And then, when it did turn, its entry was a bit too quick. So we were having to make it turn on exit, and still not have such a quick entry. That's one big thing we fought all month long — I think eventually we got a pretty good handle on it."

Mertens explains: "It's difficult to get rid of mid-corner to exit push without the car becoming loose on entry. And it's difficult to generate grip on the front end in relatively lightly loaded conditions without the car suffering on entry, because the change of direction loads the right front tyre. There is a danger of the front becoming too positive under the initial loading."

"What we strive to achieve is an aerodynamically slow entry (ie, the centre of pressure well back), with good mechanical grip from mid-corner to ▶



Above: The installation of the Chevrolet C motor. The red tubing is part of the Galles bespoke cooling system, feeding the exhaust jacket. Right: The front end of the Lola monocoque, revealing the conventional twin-shock pushrod front suspension.





GALLES AERODYNAMICIST ANDY BROWN wasted no time in preparing for the defence of his team's Indy 500 title. His 33.3% model of the 1993 Lola-Chevrolet was in Superspeedway specification for its first evaluation. It was early March when he started work on the moving ground plane in the sophisticated Brackley wind tunnel, near the Galmer Engineering facility in Bicester, UK.

### Aerodynamic Setup

Tests had already shown that the revised Speedway regulations would cut downforce by up to 25% for a given level of drag, primarily due to the loss of underwing fences. Those longitudinal 'strakes' created multiple channels in the diffuser section of the underwing, enhancing underbody airflow management.

USAC's revised chassis regulations not only banned fences, but also outlawed flush rims (wheel covers) and enforced a maximum rear wing chord of 12-inch, compared with 17-inch for the 1992 Lola wing. "The loss of wheel covers added just a little drag," remarked Brown. "The shorter-chord wing implied a higher angle of incidence, plus a higher Gurney. But that had only a slight effect. The loss of fences was the problem."

Brown is reluctant to quote actual numbers, but admits that, at Indianapolis in 1992, his Galmer G92 pulled 1140lb drag at 225mph, at which speed it generated "over 3000lb of downforce."

The aerodynamic package that Brown devised for the Galles Lola T93/01 benefited from improved flow to the rear wing, thanks to the standard car's smaller Chevrolet C engine cowling (the G92 had carried the larger Chevrolet A). Nevertheless, to regain the same level of downforce without the fences involved "A fair few modifications, ones which implied a higher overall level of drag."

Brown's T93/01 package retained the prescribed Lola nose and front wing, but not the underwing or the configuration of rear wing. Contrary to recommended T93/01 practice, Brown's Superspeedway underwing was headed by vortex generators, which he positioned at the entrance to the tunnels. The underwing itself had tunnels which were "completely different" from Lola's design. The rear wing was raised, and fitted with deeper endplates.

Brown says that his vortex generators moved the centre of pressure forward compared with the standard T93/01 configuration. He adds that raising the rear wing wing put it in cleaner air, making it more efficient. He admits that the effect, coupled with the deeper endplates, was one of working the wing harder with an implicit drag penalty. Not, he points out, as high a penalty as adding half an inch of Gurney height to the wing in its standard location — an alternative method of adding the same amount of downforce.

Brown also paid careful attention to the Lola T93/01 sidepods, modifying the radiator inlet slightly from standard. He carefully prepared for the option of running T93/07 (road racing) sidepods with their top (rather than side) air exit, reducing the size of the inlet in view of the higher speed environment.

A non-standard cooling flow on the Galles T93/01 (developed by the team) took the form of a bleed from the pod intake, which was used to cool the electronic boxes, then the exhaust jacketing.

Taking advantage of an innovation in helmet design by Bell (see *Short Take*, page 33), Brown chose the lower T93/07 screen, because this enhanced the flow to the rear wing. With a traditional helmet, the buffeting would have been too much for the driver to bear.

The team additionally modified the side head restraint that is a feature of all Superspeedway cars. "I also attended to details in some other areas," Brown adds. "But those must remain confidential, so as not to draw the attention of rival

teams..."

Brown points out that, on the T93/01, the front wing angle of attack is adjustable independently each side, permitting asymmetric settings which echo the asymmetric camber, caster, tyre pressure and other settings that are a feature of Speedway cars.

Lola T93/01 front wing adjustment is via steps of just 0.15deg. In 1992, the Galmer G92 ran with its front wings in the range 0-2deg nose-up (in which form they still produced downforce, due to the shape of their profile). The Galles T93/01 ran its front wings 0-5deg nose-down. A Gurney was fitted throughout the month of May, adjusted from zero to a 3/8-inch height in 1/16th steps.

The T93/01 rear wing has an adjustable angle of attack, an adjustable flap angle and an adjustable Gurney height. The basic design offers a quick change of flap angle and of Gurney, which slides in and out. These settings are altered during the race, unlike the angle of attack and the front wing settings.

The bespoke mounting plates for the Galles T93/01 rear wing permitted the angle of attack to be adjusted through the range 3-5deg nose-down. A standard T93/01 could not see less than 2deg nose-up. The Galles team worked with rear wing Gurneys from 1/8-inch to 3/8-inch high in 1/16th increments.

Brown's bespoke underwing was non-adjustable. Both T93/01 and T93/07 sidepod radiator air throughflow was controlled at the exit, which was kept as small as possible given the prevailing temperature. "Closing the exit means that the air rushing towards the pod sees more of a blockage," Brown remarks. "That forces more air into the underwing."

In Brown's '93 Superspeedway package, the centre of pressure moved very little on track — "Less than 1%."

The aerodynamic split between front and rear axles that was afforded by the package does not follow the weight split. "For Indianapolis, we put only 30% of the downforce on the front," says Brown. "In general terms, we want understeer, not a loose car. Ideally, we want the car close to neutral, with a bias to understeer."

### Mechanical Setup

The technical director of Galles, Alan Mertens will not be drawn on the exact distribution of weight between the four wheels of the team's T93/01. As standard, the weight distribution of Lola's Superspeedway Chevrolet car is different from that of the standard version. "Galles has its own ideas on the subject", as Mertens puts it.

In Superspeedway guise, the Lola is lighter than in road racing trim (thanks to the small wings, the lack of a differential, the carbon-carbon brakes and so forth), to the extent that it requires 25lb of ballast to bring it up to the minimum weight limit. Part of that ballast is provided by the stainless steel skidplate which replaces the regular aluminium alloy production. The rest of the ballast is lead. All Mertens would say is, "The lead is carefully placed to reflect the demands of Indy."

Mertens's version of the T93/01 retained the standard T93/01 wheelbase of 113.5-inch and the standard T93/01 front suspension, but it featured his own rear suspension. This had alternative pickup points and bespoke wishbones, offering different geometry. "It was derived from the Galmer G92," he explains. "So it was not unknown to us."

The Galles team's six-speed (no reverse) Lola T93/01 transmission was set up to provide three 'active' top gears, the lower three speeds being used only for accelerating from a pitstop. The gearbox was fed through a 23:24 drop gear and fed out to a 10:34 CWP. The first three gear ratios were 13:37, 17:38 and 17:26. Fourth gear, used for restarts, was 23:29. Fifth gear, used for run-

ning in traffic, was 21:26. Sixth gear, used for running in clean air, was 23:28.

The Galles T93/01 was equipped with "Reasonably heavy rollbars at both ends," and with springs considerably stiffer than would be employed on any street circuit. Weight transfer was consequently less pronounced — but still highly significant. "The same rules apply," says Mertens, "with greater subtlety. Also, at Indy, weight transfer is harder for the driver to perceive."

Damping likewise becomes a very subtle art. "Indianapolis has a track surface like a billiard table, so damping in the classic sense is only required for the bump between Turns 1 and 2 and over the ripples in Turn 3. But to maintain a stable aerodynamic platform, low-speed damping is very important.

"We lack quick adjustment with our (traditional-style) Koni dampers, but we do have an infinite range of adjustment. We have our own damping rig and we know how to revalve them. We put a lot of time and effort into damping, both high- and low-speed — probably more than a Formula 1 team. We have real suspension movement, even here at Indy..."

"On the Superspeedway, since the car runs so stiff and the track is so smooth, there is little shaft movement. Consequently, it is doubly important to get the required control without making it too harsh. We want to achieve the required stability of the aerodynamic package without loss of mechanical grip.

"Damping can become so extreme that it can remove mechanical grip. Cars are on a knife-edge here — a tiny change can upset a chassis. A slight alteration to the low-speed rebound setting can turn a nervous car into one with a big push."

The Koni dampers on the Galles T93/01 are wrapped by linear steel springs. "In the past we have run progressive rate rockers at the front but, this year, we have stuck with a linear wheel rate," Mertens comments. "That rate was in the region of 2400lb/in at the front and 2100lb/in at the rear."

Was droop eliminated? "I haven't restricted droop at Indy since 1988 — it is a bit harsh! Anti-dive and anti-squat? "No comment!"

For the Brickyard, the Galles Lola was set up with baseline static ride height settings of 0.8-inch front and 1.3-inch rear. Although the car sat nose-down in the pit lane, out on the circuit it ran level. Up to speed, indeed, it would brush the track surface with its skidplates both front and rear. Up to three-quarters of that loss in ride height was accounted for by tyre sidewall deflection.

In fact, the chassis was set up at a slight tilt — 0.75 to 1deg — so that the underwing ran flat on the 9deg banking. Brushing the track surface produced the maximum downforce. It was important to ensure, as far as possible, that the track was just brushed and not rubbed. Rubbing the track surface would, of course, rob speed.

Although the car was designed to brush the surface, changing its rake was a key adjustment for aerodynamic balance. "A 10-thou adjustment in ride height is sufficient to alter the balance of the car," Mertens explains.

The 1992 Indy-winning engineer emphasises that cars are on a knife-edge at the Speedway. "A change in the front wing setting of just 0.15deg can turn a car that is loose into one with a push. Similarly, a 10-thou change in spring platform height alters the ride height enough to transform the car. It is so hard to chase changing track conditions..."

At speed, clearly, wheel movement must be negligible, and so, consequently, must camber change. Mertens reports that, at the front, the Galles Lola undergoes 3.5deg camber change per 1-inch of wheel movement — quite a large amount by contemporary racecar standards — with approximately half that at the rear. The left



## INDIANAPOLIS 500 SETUP

side of the car is set with positive camber, while the right side is set with negative camber.

In the old days, IndyCars ran with their body offset to the left to help in countering the effects of weight transfer from inner to outer wheels in the turns. Contemporary regulations stipulate that the car must be symmetrical but, when running asymmetric camber settings, the car might measure symmetrical with different-length wishbones side-to-side. The Galles Lola had asymmetric wishbones at the front but not at the rear (where camber was less pronounced).

Asymmetric camber settings help the tyre contact patches to run flat on the lightly banked turns under cornering loads that can be as high as 3.3 G. As the car rolls — mainly through the effect of tyre sidewall deflection — it leans on the outside edges of its outer tyres: hence the conventional negative camber on the right side. Meantime, the inner wheels go into droop, and the positive camber that side helps to pull the contact patch flat.

Clearly, this ploy is only possible because, at Indy, the car is always turning left. Mertens observes that the most important thing is to use the camber setting to get the mid-tread and inner tread portion temperatures correct on the right-hand side. He says, "The outer portion of the tread looks after itself." Similarly, the left-hand tread temperatures can be juggled to ensure an even spread via camber adjustment.

"Camber adjustment is very important as a fine-tuning tool at the Speedway," according to Mertens, "and so is toe-in." Wheels tend to point in different directions in the static condition. At the front, the Galles Lola was set with 60-90-thou of toe-out. At the rear, it was set with 60-thou of toe-in on the right-hand side, and anything from 40-thou toe-out to 60-thou toe-in on the left-hand side.

"If the car is pushing, we can go from toe-out to toe-in on the left rear," Mertens explains. "Conversely, if it is loose, going from toe-in to toe-

out will tighten the back in."

Another factor influencing the handling is the use of tyre stagger. There is only one available Goodyear tyre — for qualifying and the race — but it comes in a range of overall diameters, for the rear. The main reason for fitting different-diameter tyres each side of the rear axle is to compensate for the lack of differential action. "A differential would upset the car on the Speedway," Mertens observes. "Traditional differentials chatter too much."

Running a spool makes the car want to drive straight on, rather than turn into the corner. But tyre stagger compensates for that. More stagger implies that the car will turn better; a reduction in stagger can be used to create understeer if the car is loose. Properly set up, the combination of spool and stagger is thought to scrub less speed than would differential action as the car changes direction.

The overall combination of tyre stagger, asymmetric camber and even asymmetric caster means that the car wants to turn left on the straight. To turn into a corner, therefore, the driver need only relax his grip on the wheel.

Not surprisingly, there are also asymmetric tyre pressures. Tyre pressures affect the appropriate camber settings and the appropriate tyre stagger. Typically, according to Mertens, Speedway tyre pressures might be 39psi on the left front, 48psi on the right front, 38psi on the left rear and 46psi on the right rear. "Tyre pressures are crucial," he emphasises. "They affect the effective spring rate at each corner and change the crossweight."

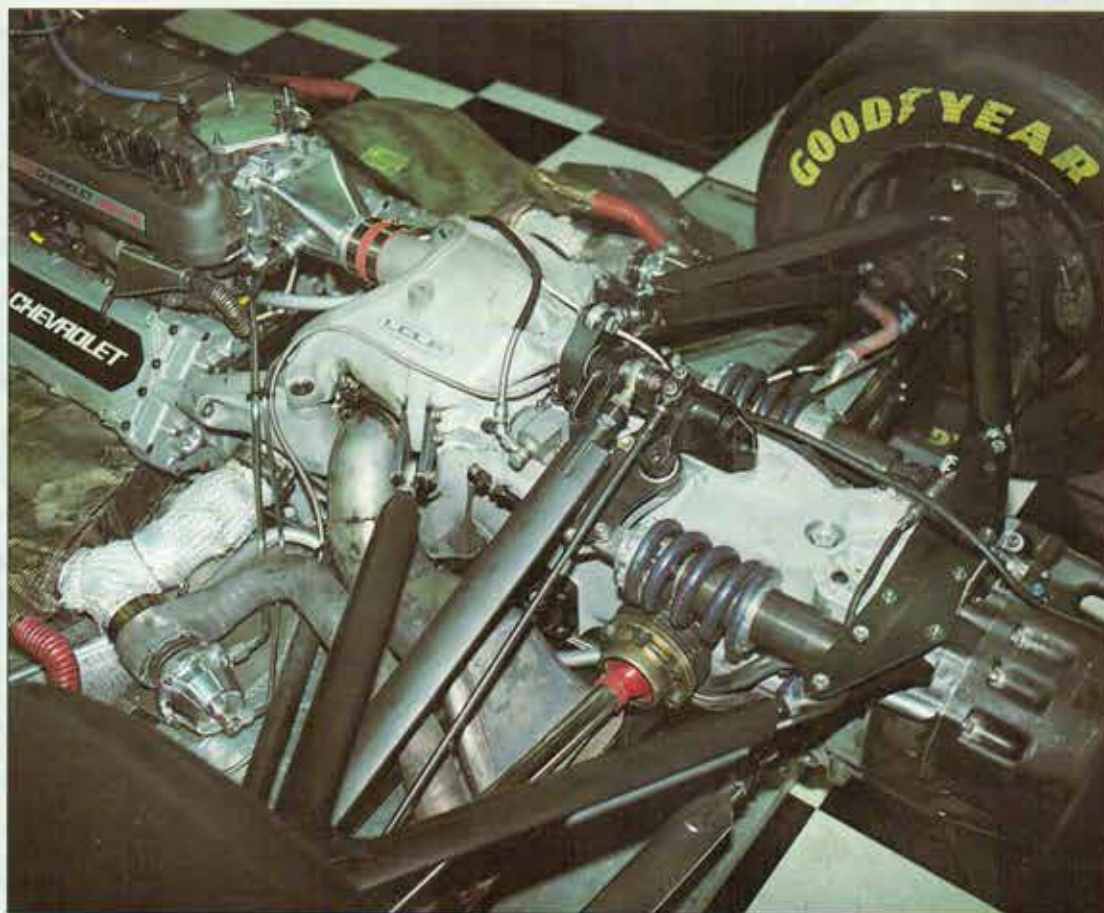
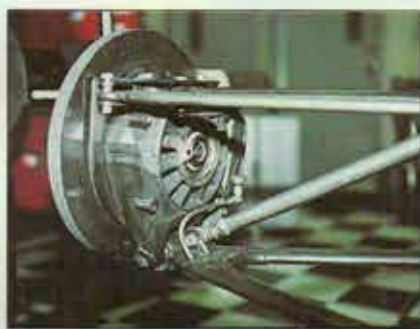
Wheel rates — and damping rates — are not necessarily the same on each side of an axle. "The back end of the car might be 'square' but not the front end, or vice-versa," says Mertens. "Sometimes the whole car can be square, sometimes not. It tends to vary throughout the month."

Mertens explains that crossweight is a major setup consideration. "If we put more weight on the

right front, the car feels more propped up at that corner. It's more comfortable for the driver but the car will tend to push more.

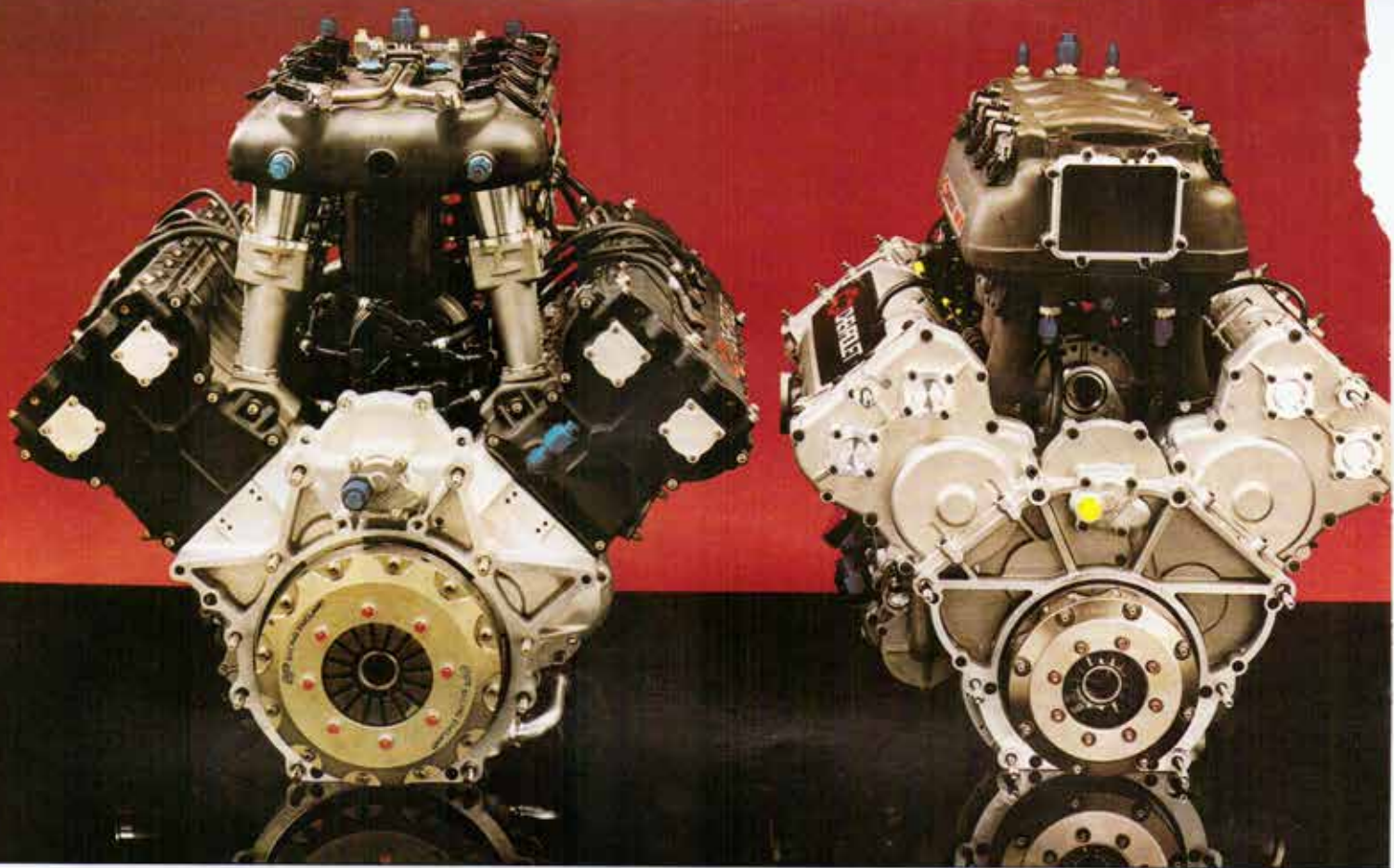
"Quite often, people try shifting weight onto the left front to eliminate mid/exit push. That is making the left front tyre do more work — and adding weight to the left front means that you're adding weight to the right rear. That situation can send a car loose on a long run — the car is turning on the right rear and will burn up that tyre faster.

"We generally start out by deciding what cross-weight we require and set the rest of the car up around it."



Top: At Indianapolis, the Lola front upright runs without cooling scoops, and carries a carbon-carbon brake disc. Above: The front of the Galles Lola underwing was headed by vortex generators, seen here as a small triangular extension to the leading edge of the sidepod. Left: The Lola features an unconventional pushrod rear suspension, incorporating twin rockers which operate rearward-facing spring-damper units.





► the exit. If the car is pushing, that kills speed..."

In theory, a car needs neutral handling to attain the maximum possible turn speed but, in practice at Indy, a neutral car feels loose (prone to oversteer) — hence "nervous" — so a degree of understeer is inevitable.

The cars were markedly more weather-sensitive this year. Each year since the track was repaved in 1988, they have become a little more weather-sensitive, and the fact that this year there was just one groove worsened the situation. That groove got dirtier faster, and the cars became more

sensitive to ambient conditions.

Heavier, more humid air can affect the level of downforce. Similarly, track surface temperature affects tyre performance. So the day can be humid and cold, humid and hot, dry and cold, or dry and hot — and each set of conditions requires a different setup. Further, the state of the groove is very significant — how dirty it is, and how much rubber is down (rubber down can increase grip when the track is cold). Overnight rain can fundamentally alter that factor.

During any given day, small changes in track conditions can affect the bal-

ance of a car. Wind is another factor. Drivers try to avoid running when it is windy, while engineers try to avoid chasing the wind. "We ask the driver to try to feel what the car is doing, taking the wind out from his mind," Mertens remarks. "If race day is windy, we add downforce. This year, the wind wasn't a significant factor."

Rain preceded the 77th Indianapolis 500, leaving the track 'green' and cool. The majority of drivers found their cars loose in the early stages. Junior's car was no exception. "We had made some changes to pre-empt that," says Brown, "but it soon became clear that we hadn't gone far enough, and the oversteer worsened as the fuel load lightened."

Changes to the Gurney height and then to tyre stagger improved the situation, pitstop by pitstop. The car was fine over the third quarter of the race, when Junior emerged in the lead.

Over the last quarter, alas, the car started to push, and that wasn't caught in time — "We didn't go far enough to compensate for changes to the track..."

Worse, Junior's late-race pitstop schedule put him towards the back of the unusually long queue of cars still on the lead lap. Pitting on lap 164 under green, then again 10 laps later for a final 'splash' under yellow, was a mistake. It seems that the car's fuel meter had been wrongly calibrated. Unsure of the validity of its readings, the team erred on the safe side. After that, due to the single groove and the short duration of the final green, passing was more difficult than ever. Junior finished less than 10 seconds behind winner Emerson Fittipaldi. In eighth place...

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NEW	OLD	NEW	OLD
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- 3 NEW GRASS BUFFER STRIP, 15' WIDE - CORNERS, SHORT CHUTES.
- 4 NEW WARM-UP LINE 22' WIDE - IN CORNERS, SHORT CHUTES.
- 5 OLD WARM-UP AREA 12' WIDE - IN CORNERS, SHORT CHUTES.

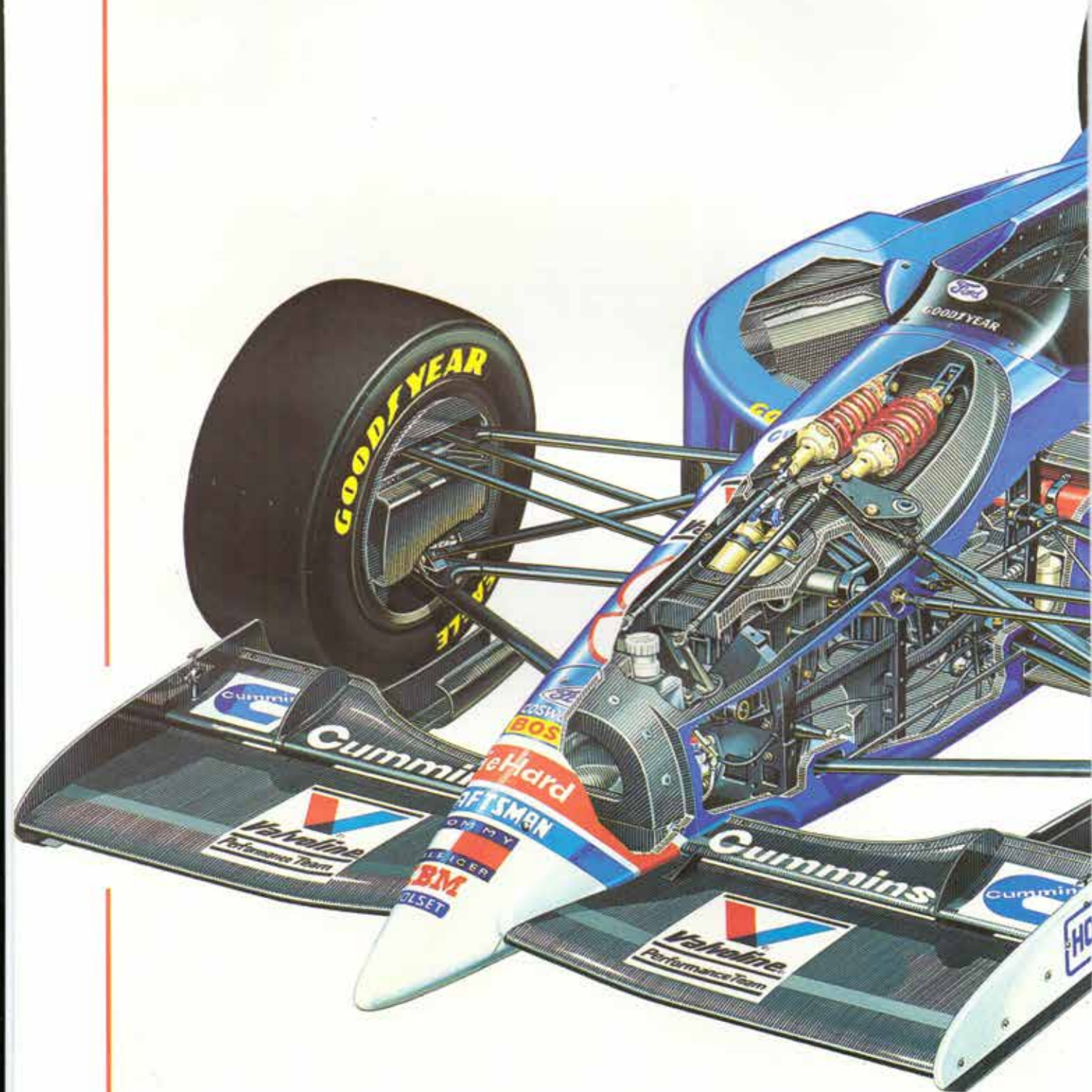
• WALL  
• FENCE



# RACECAR

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## LOLA T94/00 FORD XB









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# LOLA T94/00 FORD XB

# Specification

**T**he Lola T94/00 is the chassis with which Lola Cars is defending the PPG IndyCar World Series title that was won in 1993 by Nigel Mansell, with a Ford XB engined Lola entered by Newman-Haas Racing, the company's US works team. The new model is being raced in 1994 with Ford XB and Ilmor engines (like its predecessor), and also with the brand new Honda V8. Lola planned an initial production run of 30 and, since production commenced in January 1994, three of the \$400,000 chassis have been completed each week at the Huntingdon factory.

Ford powered examples were delivered for the action at the start of the 1994 season to Newman-Haas (for Mansell and Mario Andretti), AMS-SRS (Al Unser Snr), Budweiser/King Motorsport (Scott Goodyear), A.J.Foyt (Davy Jones and David Tennyson), PacWest Racing (Dominic Dobson and Scott Sharp), Dick Simon (Raul Boesel), and Walker Motorsport (Willy T.Ribbs, Mark Smith and Robby Gordon). Gordon's car is the one depicted in our superb cutaway illustration by Tony Matthews.

Indy Regency Racing (Arie Luyendyk and Olivier Grouillard) equipped its new chassis with the latest, D-spec engine from Ilmor Engineering, while Rahal Hogan Racing (Bobby Rahal and Mike Groff) installed the new Hondas.

Technically, the most noticeable feature distinguishing the T94/00 from its predecessor is its sequential-shift, transverse gearbox. Although Lola has created transverse transmissions for recent Formula 1 and Formula 3000 projects, the gearbox for its 1994 IndyCar is a totally new design, offering improved torsional rigidity. Close study of the 1993 series-winning T93/00 had also confirmed that a main factor contributing to its handling problems on road courses was the 150lb (68kg) mass of its outboard longitudinal gearbox, overhung behind the rear axle line. The T93/00 featured an integral gearbox and bellhousing casting, but now a separate bellhousing casting can be supplied to suit any of the three engine options. The gearbox remains the same for all applications.

The starting point of the T94/00 project came in July 1993, when three concept models were evaluated in the wind tunnel at Cranfield. "We tried to make the gearbox very small on the underside to match the underbody,"

explained Lola's joint project leader, Keith Knott. "To achieve this, we incorporated a drop gear on the front end of the gearbox. The gains shown in the wind tunnel made it clear that we really had to go for it with the transverse system."

Turning the gear cluster through 90deg has obviously created opportunities to alter the packaging at the rear of the car. The bodywork covering the rear dampers is now lower and flatter, improving airflow to the rear wing.

New rules relating to short-oval events limit the rear wing to two elements, with a maximum height of 33in (838mm). This reduction has obliged IndyCar designers to attempt to recover downforce in other areas, and has placed emphasis on underwing efficiency. Lola's wind tunnel programme for the T94/00 was the most intensive ever carried out by the company.

A constructor must supply its customers with a base vehicle that can be converted into a superspeedway car, a short-oval car, and a road course car. Each configuration requires separate wind tunnel testing. Knott: "You have to take downforce off the rear of the car to comply with the rules on the one-mile ovals. Having done that, you have to take downforce off the front, too. So for the one-mile oval kit we've come up with a shorter-chord front wing assembly to match the new rear wing."

Knott reported that the diffuser was "different" (due mainly to the changes to transmission package) but was unwilling to go into detail at the time of writing. He continued, "On road courses, we were not as good as we should have been in 1993, compared with Penske. The changes we've made give us an increase of about 17% in overall downforce."

The T94/00 is Lola's first monocoque made only with carbonfibre skins over aluminium honeycomb core material. All Lola's previous carbonfibre designs have incorporated separate aluminium-skinned sections in the area behind the front wheels. Over the years, as chassis integrity has improved, the aluminium-skinned section has decreased in size. On the new car, it has been eliminated, resulting in a small weight saving.

Working alongside Keith Knott as the joint T94/00 project leader was John Travis. Their team of 15 included departmental heads Simon Jennings (aerodynamics), Duncan McRobbie (transmission), Tony Woods (production), and Barry Hobart (composites).

Marque **Lola** Model Designation **T94/00**  
Competition Category **IndyCar** Producer  
**Lola Cars** Customer Team **Walker**  
Motorsports Specification Date **March 1994**

## DIMENSIONS

Dry Weight **703kg/1550lb** Wheelbase  
**2946mm/116in** Front Track **1994mm/78.5in**  
Rear Track **1994mm/78.5in** Overall Length  
**4953mm/195in** Overall Width **914mm/63in**  
Overall Height **919mm/36.2in** Engine  
Displacement **2650cc/161cu.in**

## COMPONENT TYPES & LOCATIONS

Chassis **Carbon composite monocoque**  
Engine **V8, turbocharged** Induction **Fuel Injection** Fuel **Methanol** Ignition  
**Customer/engine builder choice** Engine Location **Rear of monocoque** Transaxle Case **Magnesium alloy casting with inboard transverse gearbox** Gearbox **Five-speed plus reverse, non-synchro with cable sequential selection. Ovals: six-speed, no reverse** Gearbox Location **Rear of engine** Clutch **5.5in (140mm) triple-plate sintered** Differential **Salisbury-type** Driveshafts **Tubular steel with CV joints** Steering **Rack & pinion** Front Suspension **Pushrod with double wishbones & coil spring/damper units** Rear Suspension **Pushrod with double wishbones & coil spring/damper units** Dampers **Two-way adjustable gas pressurised, single-tube** Wheels **Magnesium alloy one-piece** Wheel Diameter **15in (381mm)** Brake Discs **Cast-iron, outboard, ventilated. Superspeedways: carbon-carbon** Brake Callipers **Single, six-piston** Brake Pads **Carbon Metallic** Water Coolers **Two sidepod-mounted radiators** Engine Oil Coolers **One heat exchanger in left sidepod** Oil Tank Location **Between fuel cell & engine** Fuel Tank **Single-cell with nylon ballistics felt outer liner** Fuel Tank Capacity **40 US gallons** Fuel Tank Location **Central** Bodywork **Carbonfibre & honeycomb composite** Aerofoils **Carbonfibre & honeycomb composite**

## COMPONENT SUPPLIERS

Engine **Cosworth XB** Cylinder Block **Cosworth** Cylinder Heads **Cosworth** Crankshaft **Cosworth** Pistons **Cosworth** Piston Rings **Cosworth** Con Rods **Cosworth** Valves **Cosworth** Camshafts **Cosworth** Spark Plugs **Bosch** Fuel System **Cosworth** Lola Exhaust System **Lola** Turbocharger **Holset** Chassis Fabrication **Lola Composites** Composites **Lola Composites** Gearbox **Lola** Gears **Hewland** Bellhousing **Lola** Differential Case **Lola/Hewland** Differential Internals **Lola/Hewland** Clutch **AP Racing** Brake Discs **Lola** Brake Callipers **AP Racing** Brake Fluid **AP Racing** Brake Pads **Performance Friction** Master Cylinders **AP Racing** Steering Rack **Jack Knight** Driveshafts **Lola** Driveline Joints **Lola** Wheelbearings **INA** Wheels **Lola** Tyres **Goodyear** Fuel Cell **Goodyear** Fuel Pump **Cosworth** Oil Tank **Lola** Oil Pump **Cosworth** Dampers **Koni** Coil Springs **Rockwell** Water Coolers **Lola** Oil Cooler **Garretson** Hoses **Undisclosed** Hose Connectors **Undisclosed** Rod Ends **Goldline** Fasteners **Undisclosed** Instruments **PI Research** Data Acquisition **PI Research** Telemetry **Ford Electronics** Starter Motor **Die Hard** Battery **Cosworth** Radio **Motorola** Steering Wheel **Momo** Seat Harness **Simpson** Fire Extinguisher **Lifeline**



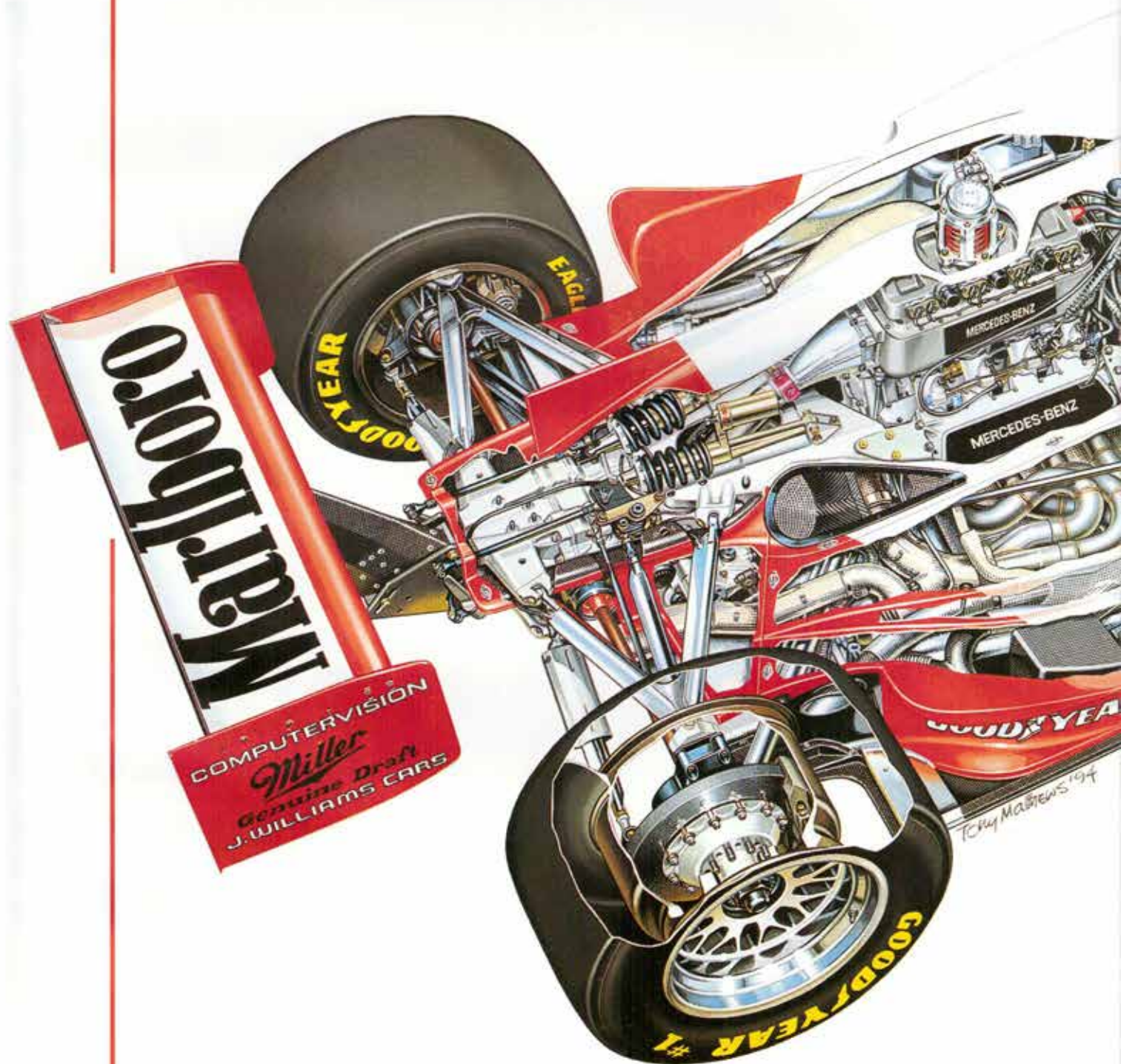
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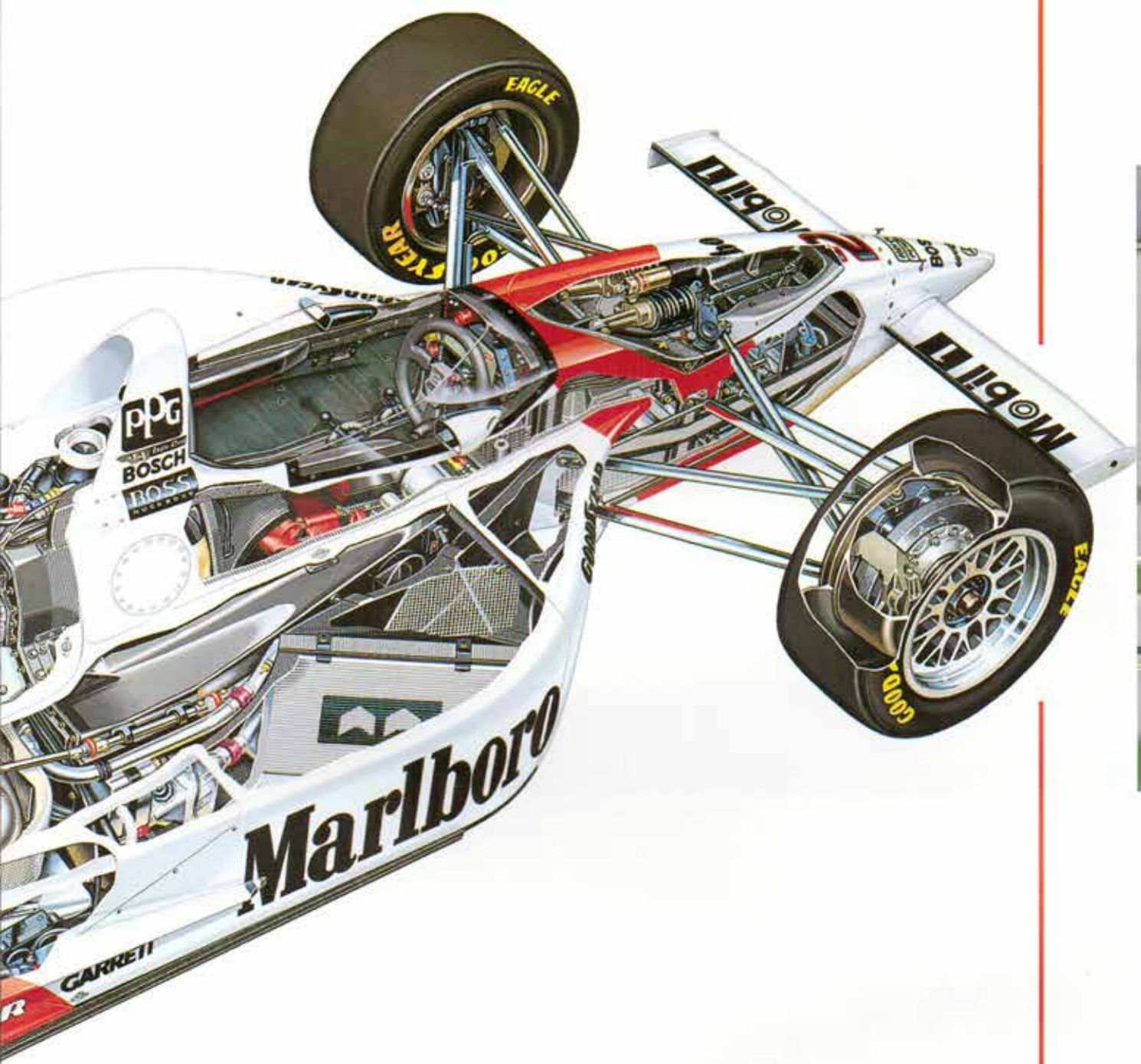
# RACECAR

ENGINEERING

## PENSKE PC23 MERCEDES-BENZ

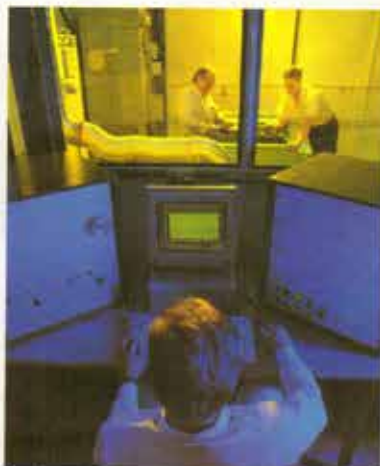








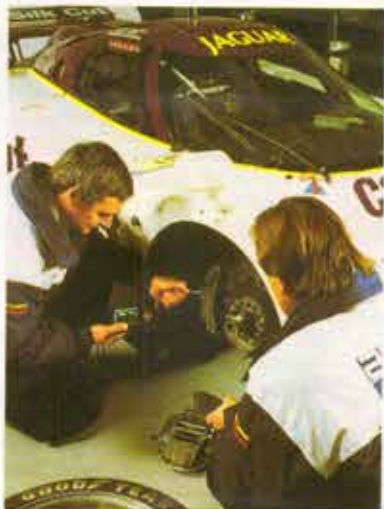
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# PENSKÉ PC23 INDYCAR

By QUENTIN SPURRING

**T**he Penske PC23 is a landmark racecar for the accomplished Penske organisation. In 1994, Penske Cars celebrates the 20th anniversary of its debut as a racecar constructor, and the PC23 is the first of its products intended for the new IndyCar racing partnership between Marlboro Team Penske and Mercedes-Benz.

Before starting to produce its own racecars in 1974, Roger Penske's team had achieved many successes over an exceptionally wide range of track racing disciplines. Its raceshop in Reading, Pennsylvania, had established a strong reputation for creating consistent winners from 'customer' racecars, by deploying very high standards of development and preparation. The team won with cars produced by AMC and Chevrolet in the Trans-Am, Lola in the USRRC and then Lola, McLaren and Porsche in the Can-Am, Lola and Ferrari in Sportscar racing, Eagle, Lola and McLaren in IndyCar racing, and McLaren in Formula 1 - all of them raced by Penske's stalwart driver, Mark Donohue.

When Penske took over specialised UK factory premises in Poole, Dorset, a Cosworth DFV powered Formula 1 car was the first project undertaken there. The PC1 was ready for the last two Grands Prix of 1974, and had its first race, in Donohue's hands, at Mosport Park, Canada, that September.

Penske again ran the PC1 in 1975, but suffered a terrible setback when Donohue crashed fatally in Austria, at the wheel of a March that was being used while the new PC3 was on the drawing board. Donohue's death was a serious blow, but the team's professionalism saw it through the crisis. It continued in Formula 1 until the end of the 1976 season, in which John Watson, with the PC4, won the team's only victory. It came in Austria.

All subsequent Penske chassis have been designed and built in Poole for IndyCar racing. They have helped to take the team's tally to a record 81 race wins (including no fewer than nine in the Indianapolis 500), and eight championships won by Tom Sneva (1977-78), Rick Mears (1979-81-82), Al Unser Snr (1983-85) and Danny Sullivan (1988).

Emerson Fittipaldi won the 1989 title with a PC18 owned by Patrick Racing but, as a team, Penske Racing has gone five seasons without winning

the PPG IndyCar World Series. Virtually an all-new car, the PC23 is intended to end that run. Its design by Nigel Bennett sets out to optimise the best features of its predecessor, and reflects the attention to detail for which Penske Cars is rightly admired. Unlike the PC22 of 1993, the new car is being raced only by its constructor, which has formed a three-car 'superteam' - Fittipaldi, Paul Tracy, Al Unser Jr - in a bid to wrest the title from Lola Cars.

When its involvement was announced, Mercedes-Benz declared that it did not intend to badge the Ilmor Engineering engines until 1995, and normally the PC23 is equipped with the latest version of the turbocharged 2.65-litre, 32-valve, four-cam Ilmor 265D V8. For the 1994 Indianapolis, however, the team and its partners stole an unexpected march on the opposition.

It was one of the best-kept secrets in motor racing when Ilmor completed and extensively tested an all-new, turbocharged, 3.4-litre, 16-valve, pushrod V8, known as the Mercedes-Benz 500L. Taking advantage of relaxations to the USAC rules governing so-called production-derived engines, the team hoped that it would give its cars an advantage at Indianapolis of well over 100bhp.

Tony Matthews's superb cutaway illustration overleaf depicts the low-downforce 'Superspeedway' version of the PC23 as prepared for Indianapolis, with the new Mercedes-Benz engine.

The PC23 can be easily adapted to take either of these engines, although the pushrod unit is slightly taller. The distinctive fin on the engine cover comes as part of the packaging for the taller engine. During wind tunnel tests, however, the team found that it offered a small aerodynamic advantage, so it was also adopted for the short-oval version of the car in the second round of the 1994 series, at Phoenix. At Indianapolis, USAC officials asked the team to trim 8in from the rear end of the fin, so that it did not extend beyond the rear axle line. The Indianapolis car features a stronger and slightly wider version of the team's highly effective, transversely mounted gearbox.

Marlboro Team Penske embarked on its 1994 Indianapolis programme with Fittipaldi and Unser Jr sharing the lead of the series, each already having won a race (at Phoenix and Long Beach respectively).

## Specification

Marque Penske Model Designation PC23  
Competition Category IndyCar Producer Penske Cars

### DIMENSIONS

Weight 1550lb (road course, short oval) 1500lb (Superspeedway) Wheelbase 117in Front Track 78.5in Rear Track 78.5in Overall Length 195in Overall Width 63in Overall Height 36in Engine Displacement 2650cc (Ilmor 265D), 3430cc (Mercedes-Benz 500L)

### COMPONENTS

Chassis Carbon honeycomb composite mono-coque Engine V8 Induction Turbocharged Ignition Undisclosed Engine Location Rear Transaxle Case Penske Gearbox Transverse Gearbox Location Rear Inboard Clutch Four-plate Differential Limited-slip or spool Driveshafts Tubular steel with CV joints Steering Rack & pinion Front Suspension Double wishbone, pushrod operated coil spring damper units Rear Suspension Double wishbone, pushrod operated coil spring damper units Dampers Three-way adjustable Wheels Magnesium alloy Wheel Diameter 15in Brake Discs Steel (road course, short oval), carbon-carbon (Superspeedway) Brake Calipers Four-pot Brake Pads Carbon Metallic (road course, short oval), carbon-carbon (Superspeedway) Water Coolers Two side-pod-mounted radiators Oil Coolers One heat exchanger mounted in left sidepod Oil Tank Location Between fuel cell & engine Fuel Tank Single-cell Fuel Tank Capacity 40 US Gallons Fuel Tank Location Central Bodywork Carbon/honeycomb composite

### SUPPLIERS

Engine Ilmor Engineering Engine Preparation Penske Racing Crankshaft Ilmor Pistons Ilmor Piston Rings Ilmor Conrods Ilmor Valves Ilmor Camshafts Ilmor Engine Management System Magneti Marelli Ignition System Undisclosed Spark-plugs Bosch Exhaust Penske Radiators Penske/Modine Chassis Fabrication Penske Composites Penske & DPS Components Gearbox Penske Gears Various Bolthousing Penske Differential Case Penske Differential Internals Xtrac Clutch AP Racing Clutch Fluid AP Racing Brake Discs Alcon Brake Calipers AP Racing Brake Fluid AP Racing Master Cylinders AP Racing Brake Pads Performance Friction (road course, short oval), AP Racing (Superspeedway) Driveshafts Metalore Wheel Bearings Timken Wheels BBS Tyres Goodyear Rod Ends Various Fasteners Various Fuel Cell Goodyear Fuel Pump Ilmor Fuel Ashland Chemicals Lubricants Mobil Oil Pump Ilmor Coil Springs Hyperco Wiring Harness Pi Research & Ilmor Battery Delco Starter Motor Undisclosed Radio Motorola Data Acquisition Pi Research Telemetry Pi Research Instruments Pi Research Steering Wheel Personal Seat Penske Seat Harness Williams Fire Extinguisher SPA

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## REYNARD'S DEBUT INDIANAPOLIS 500

Reynard Racing Cars entered IndyCar racing in 1994 with an extraordinary record to defend: debut victories in every track racing category that it had contested. Even so, it was against most expectations when Michael Andretti kept the record intact by winning in Australia. In its first Indianapolis 500, Reynard continued to unsettle the IndyCar establishment by gaining an impressive second place. All but Penske's powerful 'Dream Team' had to

# FOLLOW THE FOX

By ALAN LIS

**E**very one of the 14 Reynard 941 Indycars that had been built were presented at USAC technical inspection for the 78th Indianapolis 500. Half of them were deployed as spare cars. The other seven all qualified for the race. Five were running at the finish.

The Ford XB engine equipped the cars of Chip Ganassi Racing (driven by Michael Andretti and Mauricio Gugelmin), Forsythe-Green (Jacques Villeneuve), Hayhoe Racing (Jimmy Vasser) and Hemelgarn Racing (Stan Fox). Those of Galles Racing (Adrian Fernandez) and Hall Racing (Teo Fabi) were powered by the Ilmor 265D.

In designing the 941, of course, Reynard's chief designer, Malcolm Oastler, had to evolve a chassis that would easily adapt to both engines, while also allowing for IndyCar racing's three distinct chassis packages – road/street course, short-oval, superspeedway.

The 941 chassis, which is made from carbon laminated over aluminium honeycomb core material, is altered to accept the Cosworth or the Ilmor with a kit consisting of a different rear bulkhead and fuel cell. There are also differences in water rails and exhaust pipes, but the engines have similar dimen-

sions and weight. The same Reynard gearbox is used, although the casting, which is in L155 aluminium, is machined to suit. Unlike the latest Lola and Penske, both of which have inboard transverse gearboxes, the Reynard has an outboard longitudinal transmission, with Hewland internals and a manual sequential shift. The 941 is equipped as standard with AP Racing's three- or four-plate, 5.5in diameter carbon clutch.

The superspeedway package comprises unique, anhedral nose and the regulation smaller rear wing, as well as slight alterations to the sidepods. "The underbody is the same one that we use on short-ovals," commented Oastler at Indianapolis. "It's not a specific superspeedway underbody, but it produces more downforce at low ride heights than the road course underbody. It doesn't have to cover such a wide range: we don't run a 2in ride height around here.

"On the superspeedway sidepods, we can reduce drag with different radiator exits. We also shuffle the weight distribution about by changing the wheelbase." The wheelbase is adjustable in the range 113.7-119.3in (2890-3030mm) by altering the angles of the wishbones in the pullrod/rocker arm suspension to offset the wheels back-

wards or forwards.

For Indy, the gearbox has six ratios with effectively two top gears, one acting as an overdrive, and the differential is replaced by a 'spool'. The standard AP Racing metal matrix, six-piston brake calipers and Carbon Metallic pads grip Hitco's 325mm diameter, 28mm thick carbon-carbon discs. These changes and the smaller wings mean that the superspeedway 941 is much lighter than the higher-downforce car: about 50lb (23kg) of ballast was needed to get the cars to the minimum weight.

Reynard's policy at Indy was to place its own engineers with its customer teams. The principal of Reynard North America, Bruce Ashmore worked with Ganassi, liaising with all the teams. Oastler was with Hall, and other Reynard personnel assisted the teams' regular race engineers. These latter were Julian Robertson and John Bright at Ganassi, Tony Cicale at Forsythe-Green, David Cripps at Hayhoe, Ron Dawes at Hemelgarn, Ed Nathman at Galles, and Bill Pappas at Hall.

Running out of premises in Indianapolis, Chip Ganassi Racing is Reynard's works development team. It had the first development chassis, 001, and succeeding cars have differed in many areas. "That's the way Reynard works," said Michael Andretti's race







engineer, Julian Robertson. "They've made a whole range of improvements that have then appeared on the customer cars. In a programme like that, literally hundreds of parts are upgraded. After three or four chassis, a 'standard' package was evolved, but there's still a big development programme going on.

"For Indy, we run different suspension geometries and so on, but that's all built into the car anyway. This car is certainly flexible in terms of suspension geometry but, aerodynamically, the teams are limited to changing details."

Reynard does the wind tunnel tests in the UK and ships revised parts to its teams quickly. It also provides the wind tunnel figures for the aerodynamic packages, and then the teams do their own work in evaluating that information. Naturally, the teams can evolve their own variations on Reynard's aerodynamic themes and it was noticeable at Indy, for example, that the Penskes' fin-like engine covers were quickly imitated on the Reynards driven by Andretti, Fernandez, Vasser and Villeneuve.

The design of the 94I was started in March 1993, and a model first ran in the wind tunnel that May. Reynard's engineers started their aerodynamic programme with the road course pack-

**The most magnificent of Reynard's seven at the 1994 Indianapolis 500: the Forsythe-Green entry of rookie Jacques Villeneuve, who finished a strong second.**

age, but also ran a few tests of the superspeedway configuration early on. Oastler: "We fitted speedway wings and had a look at the pitch-sensitivity and the heave-sensitivity (yaw) and the drag figures, just to see what we had. We really got serious about the speedway kit towards the end of the year. We spent the last three months of 1993 developing it in time for Ganassi's first run at Indy in March 1994.

"The anhedral front wing form was one of the first things we tried in the tunnel. It was more of an advantage then than it is now, because we've since developed the rest of the car. What the anhedral wing does upstream works with what's downstream on our car. It probably wouldn't work on a Penske or a Lola.

"We didn't need to change the package much as a result of our track testing. We machined the rear wing adjusting slots another 40-mil, so that we could back off the wing a little more, but that's about all. So the spec that we're running is really what we developed and settled on last December. When we first ran at Indy, the temperature was 50-60degF (10-16 deg C), with lovely, dense air. We ran round easily flat, and went 228mph. But we had to wait for the weather to get hotter before we could find out how the car

was going to run in May."

The USAC regulation front wing controls pitch-sensitivity quite effectively. The road course and short-oval Reynard, with the big front wing, is currently much more pitch-sensitive. Reynard is currently working on that aspect of the 94I. The company is devoting six days each month on its Indycar wind tunnel programme at Southampton, and might establish a customer programme in the USA in 1995.

During May 1993, teams found it hard to evaluate the level of downforce that was needed, because new alterations had been made to the track. Some Lola customers ended up making their own parts, having judged that the standard parts allowed insufficient adjustment. Robertson: "This year, we were aware of that problem, so we tested at Indy, and found the area in which we needed to operate. Then the customers were supplied parts that would fit straight on and be right.

"The speedway package is so efficient, it's very hard to improve it. On a road course or a short-oval, there are plenty of little tweaks that can give performance increases. But here you really notice the similarity between all the cars. That's partly due to the regulations, partly because the rear wing is ▶



► so efficient. Changes to the bodywork and underwing are always less effective than changes to the rear wing. It's difficult to get a higher lift/drag ratio here, so you have to do a lot of testing to get even the smallest benefit."

According to the teams that had switched to Reynard from Lola, the 941 has substantially more downforce than the '93 Lola – as much as 15-20%, which implies at least 3600lb (1633lb) at top speeds. Robertson: "The Reynard is a massive improvement over the '93 Lola – but so is the '94 Lola! That's because the stakes were upped by Reynard coming into the series. It's that simple."

In 1994, more drivers could run their cars wide-open all the way around the 2.5-mile Speedway. Robertson: "In 1992, on the old circuit, it was easy – you could even get rookies flat. In 1993, only a few of the guys were flat. This year, the cars have progressed and this is the second time on the new track, so more drivers are running flat. But flat isn't necessarily the optimum. The weather and the track itself change, so you're oscillating around a kind of 'mean' setup. But it is possible to run wide-open, and the quick men do in qualifying."

Aerodynamic fine-tuning is easier on a speedway, because pitch-sensitivity is less of a factor than is the case with the higher-downforce package. Robertson: "On a short-oval or road course, you can easily get it wrong. It's a lot harder to mess up on a speedway, even though you're much nearer the limit, so that small things have a big impact. The difference between the top teams and the slower teams is still the same kind of increment in effort required to get there. On a road course, you get teams running 3sec off the lead pace because they've messed up big-time. Here it's easier to get into the ballpark, but then you get into the real finesse, *really* knowing what the car does."



Michael Andretti ran strongly for Chip Ganassi Racing, offering the strongest early challenge to the victorious Penske team.

The amount of data that can be generated at Indy makes it a racecar engineering heaven. Robertson: "You can pore over the data all night. It's really neat. If you sat down to design a test track to get good data, you'd probably come up with a place with long straights and fast corners that are all the same. That exactly describes Indy. You can analyse things down to the most nitty-gritty detail."

By the end of May, the teams have had plenty of time not only to opti-►

**THE FORSYTHE GREEN TEAM** took a gamble when it chose Reynards for its return to IndyCar racing in 1994. If the decision was vindicated by Jacques Villeneuve's standout qualifying run at Indianapolis, to the inside of the second row, it was turned into something of a triumph by his second-place finish in the 500 Miles.

Villeneuve's race engineer, Tony Cicale observed: "I think everyone on the team is happy with that decision! I'm really pleased with the car. Malcolm Oastler has done a very nice job. I wouldn't say it's a revolutionary car, but it's nicely detailed and good to work on. In terms of reliability, the car has been very good here. The engines and gearboxes have been very reliable. And the performance certainly seems more than adequate..."

From the outset of the month of May, the team's philosophy was to keep its 941 as basic as possible, to provide its rookie driver with a car that he could trust day to day, and to optimise the setup by giving Villeneuve a feel for the circuit with as much track time as possible. One of the smaller teams in the series, Forsythe Green does not have the resources or the engineering staff of a Penske Racing or a Newman-Haas. Consequently, like the other Reynard teams, it relies on the factory's ongoing development programme, in which information is shared among the customers.

With the exception of Ganassi's 'works' development car, the 941 chassis which ran at Indy were virtually as delivered from the Reynard factory – except for one feature: UK-made Dynamic dampers were originally fitted as standard to 941s, but all the teams replaced them. The dominance of the Penske Racing Shock in the IndyCar series, combined with a lack of technical support for the Dynamic unit, was cited by most teams as the reason for switching.

On dampers, Cicale went his own way: "At the moment, we're running Konis. We shied away from the Dynamics primarily because we don't know a lot about them. As a new team, with a new driver, we're going to a few circuits where we haven't been before, but many that we have. Most of my setup references for those tracks are based on Konis."

"The Koni we are using is quite an old design – almost an antique damper by current standards – but it has real nice characteristics. The only disadvantage is that it doesn't adjust very quickly. To do low-speed bump adjustments, for example, it requires disassembly. But except for the time constraints, I think the Koni is pretty current, in performance anyway."

Cicale was pleasantly surprised by the Reynard's sensitivity to changes: "In speedway trim, it has been a nice car to work on. It seems to be sensitive, but not excessively so, which is sometimes quite difficult to achieve. You can have a racecar that is overly responsive, which makes it difficult to get your setup right."

Handling at Indianapolis is influenced by a number of factors. As on any circuit, weight distribution, wheelbase length, ride heights, rollcentres and spring rates are significant. The special demands of oval tracks add further complication in the form of tilt, crossweighting and tyre stagger. The interaction between these mechanical factors is then compounded by aerodynamic loads and track and climatic conditions unique to The Brickyard.

Around 50lb (22.7kg) of ballast was needed to bring the Reynard up to the USAC-specified minimum weight. On the Forsythe Green car, careful positioning of this ballast within the main chassis structure, and the choice of a relatively long wheelbase at 115.75in (2940mm), resulted in a front-rear weight distribution of between 40-60 and 43-57%. Crossweight figures were not disclosed.

The Reynard's ride heights are determined by three measurements at left-front and right-front to set tilt (side to side) and on the centreline of the rear axle to set the rake (front to rear). Cicale: "We try to be accurate to within 5- or 8-thou (0.13-0.20mm). We can duplicate that pretty regularly. We look at ride heights very carefully: the car is very sensitive in that area. At Indy, a typical difference in tilt would be roughly 0.6-0.7deg."

"The amount of rake depends on your setup and the springs that you select. For our car, which is probably typical, it's in the range of 0.4-0.5deg difference between front and rear."

Indy's mostly smooth track surface and high aerodynamic loads dictate relatively stiff spring rates – in the 2000-3000lb/in (35.7-53.6kg/mm) range.

The rollcentres used at Indy are quite different from those at other tracks on the PPG IndyCar World Series. Although reluctant to quote figures, Cicale confirmed that the difference is measured in inches: "There's a significant difference between what we run here, on short-ovals, and at a place like Long Beach. There are three or four different rollcentre height configurations that come as standard with the Reynard. We go through the various combinations at each circuit."

Tyre stagger is a feature unique to oval racing and of overwhelming importance. Cicale: "You can't even begin to work on your racecar unless you have stagger that is suitable for your driver and your setup. If you're looking for a stagger of 0.30in, but end up with 0.26in, there is almost no sense in running. It dominates the setup that much. Four-hundredths out on the stagger can totally destroy the racecar in terms of handling."

"The main problem with stagger is that it is continually changing through a practice run or a race. A car that's loose (understeering) may start out with a big stagger and, because it's loose, it will get bigger. If the car is pushing (oversteering), the stagger will probably reduce. One drives the other: the balance of the racecar drives the stagger, and the stagger drives the balance of the racecar."

At Indy, the optimum setups for qualifying and racing can be very different. For the race, Cicale favours a slightly pushing car: "A push is desirable because, with a loose car, you lose a tremendous amount of time. The perfect setup would be if the car was neutral at all times but, because of varying track conditions, that's not going to happen. If the car goes to the 'loose' side of neutral, you're slowed a lot more than if it goes to the 'push' side of neutral. So you tend to set up the car with some push in it, just because you're not really sure what it's going to do from the beginning to the end of the run."

"Overall, the optimum setup in terms of performance is probably slightly loose, which is how a lot of cars are set up for qualifying. In terms of having a consistent racecar, with which your driver will consistently do better lap times, a slight push is an optimum setup for the start of the race."

Having made his name as a racecar aerodynamicist (in the Can-Am series in the mid-1970s), Cicale might have been expected to





Tony Cicale, race engineer of Indianapolis-based Forsythe-Green Racing.

add his own variations to the Reynard package. On the contrary, "Nowadays, I don't think the average customer team can do a better job than the people who design the racecar. They do spend a whole lot of time in the wind tunnel. But the rules are very restrictive on the aerodynamic side so, even if you know exactly what the manufacturer has done in the tunnel, the gains that you'll make are generally going to be small. I love aerodynamics, but it's very costly to go tunnel testing, and it's not cost-effective for a team at our level. The money could be better spent elsewhere; we get more performance for our dollar by doing other things with it."

Cicale's Indy aerodynamic package was basically as standard. Like Ganassi, Galles and Hayhoe, the team devised a modified engine cover incorporating a tail fin, but that was really the only feature that it had on its car that Reynard had not supplied. Cicale: "We went for the fin simply because we'd found that we were marginally quicker with it. We didn't really evaluate it with a proper test programme. The USAC rules only allow the

The super-speedway Reynard 94I features distinctive anhedral nose planes, developed in the wind tunnel from the outset of the programme.

fin to extend to the rear axle centreline, so its efficiency is reduced relative to what it can do under CART's rule. When we originally did the fin, we weren't aware of that: USAC didn't let anyone know until the 11th hour, so all the fins that were in production had to be cut short. I didn't expect a significant difference in feel, and Jacques didn't notice any balance change. I think the biggest benefit might be the extra advertising space..."

A racecar that is set up to allow the driver to lap the Speedway wide-open can have too much downforce, compromising straightaway speed. Cicale: "That has always been the case here. Downforce comes with the penalty of induced drag, which is very significant in a place like this. You want to minimise drag due to negative lift, so you try to optimise your mechanical grip so that it allows you to run the lowest possible downforce. Then you can go along the straightaways quicker and, if you can still run the turns flat, it's ultimately going to give you the quickest lap time. You try to run barely, barely flat."

"Running downforce in the race seems to make sense, but passing is very difficult here: therefore you need a racecar that goes down the straightaways quickly, because that's really the safest place to pass – sometimes the only place to pass. The circuit is different relative to two years ago, when you could pass actually in the turns and run two abreast – and with a bit of a gamble, sometimes three abreast. Now it's virtually impossible. You don't really have any option other than to follow your man into the turn, try to pass him on the exit."

With the chassis setup on which the team settled, Cicale estimated that the total aerodynamic load on the car was in the range of 3500-4000lb (say 1600-1800kg) at 200mph (320kmh). "It depends on the weather. On cool, crisp days, it's probably more towards 4000lb. On humid days, especially if you're in turbulence, it's probably below 3500lb. It does vary considerably. The wind tunnel data doesn't suggest that it's that high, but the load data that we accumulated seemed to indicate that it was."

The aerodynamic split varied from team to team, but it didn't go much below 30% on the front and not much higher than 34-35%. Most teams ran within that range, the exact figure

depending on the driver, on the setup, on the weather...

The maximum straightaway speeds that were seen by Forsythe Green over the entire month of May were 238-239mph, most of Villeneuve's 'good' laps being in the 235-237 range.

The minimum corner speeds were 220-221mph on good laps. "When it get hot and slippery, that's significantly reduced. You might be looking at the low 200s under certain race conditions. So it varies tremendously. If you do a wide-open lap around here, which most of the quick guys have done in qualifying, your lap speed will be in the 226-228 range."

"The effect of the ambient temperature is much more significant than you would ever expect by doing any calculation. These racecars are very, very sensitive to temperature. I'm not sure exactly why, or the dynamics of it. Obviously it's partly aerodynamic but it's much, much more complex than that. It has something to do with the overall grip of the car. On hot, humid days, you can struggle to do 215, whereas on a fairly cool day you can do 225, no problem."

"I remember an incident a couple of years ago when I was running Mario Andretti at Newman-Haas. Mario was doing a full tank run, maybe 25 laps. It was a bright, cloudy day and, at the beginning of the run, he was doing 215, 215, 215. Then a cloud just shaded the sun for a very short period of time. As soon as that happened he went to 217, 217, 217. Then the sun peeked out from behind the cloud, and it was back to 215, 215, 215. It was frightening, the sensitivity. You would have said it was impossible. The car was almost light-sensitive rather than temperature-sensitive. It's hard to believe that the cars can be affected by the sun popping out from behind a cloud, but that's really no exaggeration..."

Wind direction and strength are also very significant: they make the turns quite different. If there is a tailwind, the car will tend to understeer into a turn. If there is a headwind, it will tend to oversteer. If there is no wind, the team might be able to achieve an almost perfect balance in all four corners, but any wind will affect the balance from one corner to another. Cicale: "I would say that the Reynard is at least as stable as the Lola and Penske in the wind, perhaps even more so. It has been a fairly breezy month here, I wouldn't say a windy month, and the car hasn't really been adversely affected by the breeze. The balance does change from turn to turn, but the crosswind sensitivity is not high."

Cicale was pleasantly surprised by the behaviour of the Reynard in traffic. During practice, Villeneuve made a point of running close behind Mario Andretti's Lola for several laps in the heat of the day, and found that the 94I did not seem to be adversely affected. However, running behind one other car is quite different to running with 32 which are continually circulating in a pattern around the track, all making a residual turbulence. Cicale: "During the month, the tendency is to run by yourself, stay out of trouble. But it is important to find out about the characteristics of the car in traffic."

"The car stayed relatively consistent throughout the entire month. We found a reasonably good setup at the beginning of the first week, and we pretty much stayed with that, regardless of the conditions, except that we changed the car a little on full tanks."





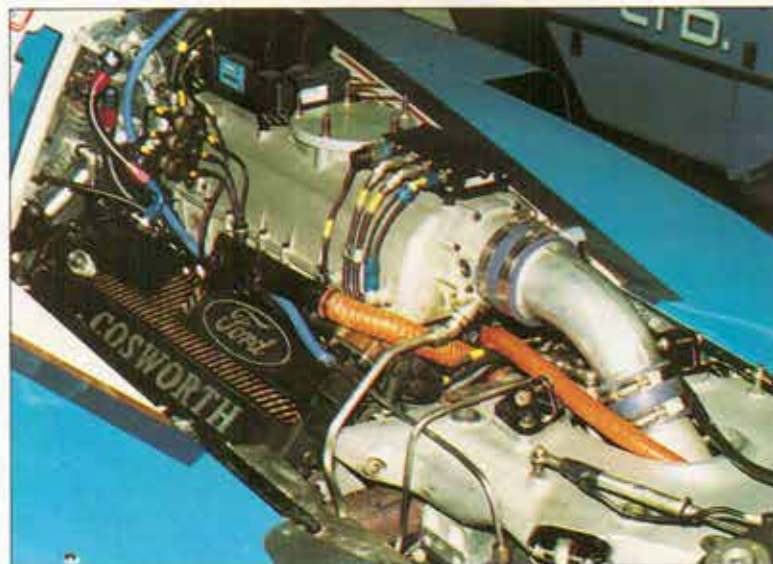


► mise the car package in terms of straightaway and corner speeds, but also for virtually any change in the weather. Robertson: "There are a million and one things to play with on any oval to set up the car. Every little thing will make a difference. Here at Indy, the top teams have everything highly optimised by the time they get to the race. For instance, we know what settings we want for any ambient temperature. Come raceday, we can put on the correct setup for that temperature, track grip and tyre stagger. That's why all the serious teams run when it's hot, when it's cold, and when it's in between: they need data for all the different scenarios."

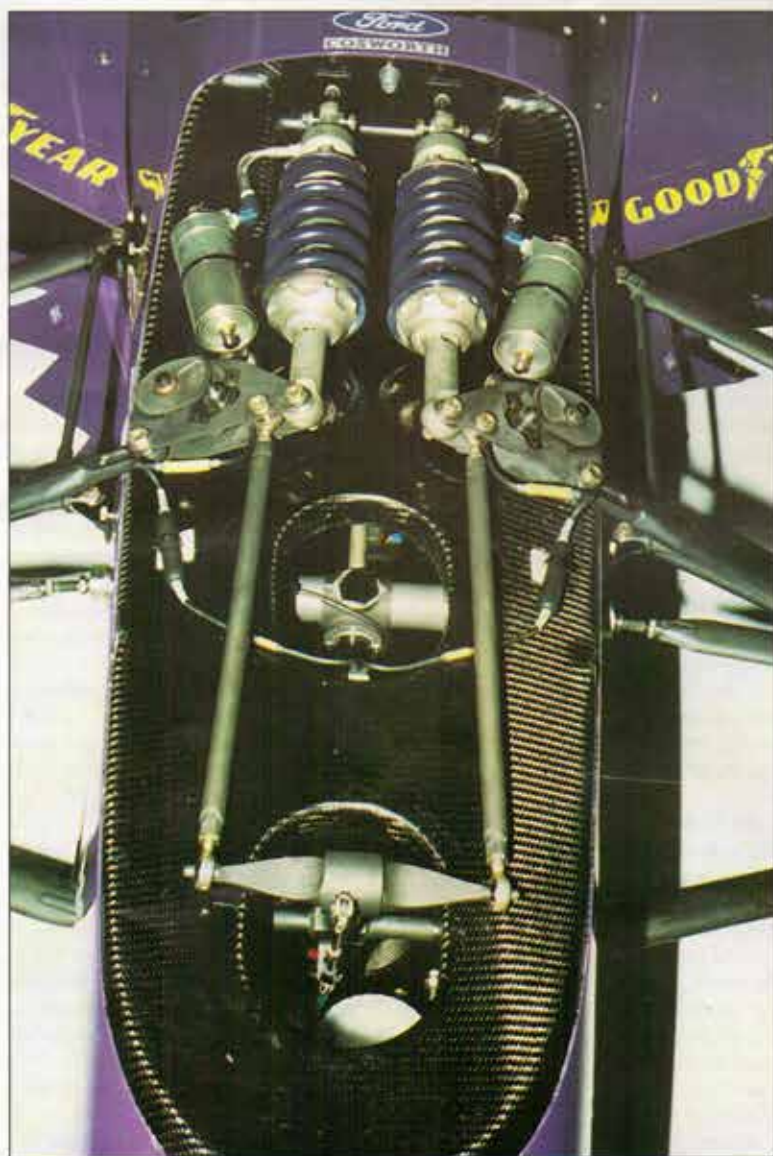
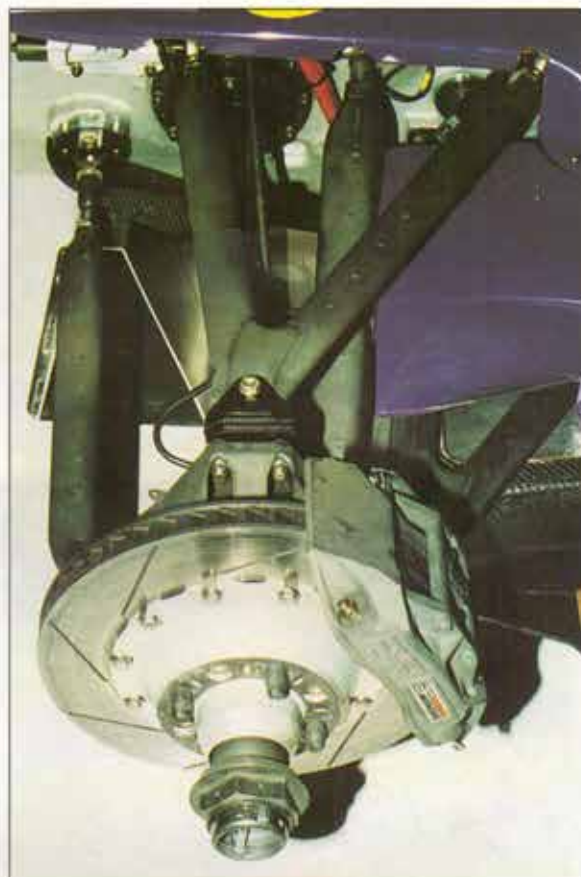
"The big teams are festooned with gadgetry, running a phenomenal amount of data acquisition. Once you *really* understand your car, you can optimise it and keep at that level. But the smaller teams which may not have all that backup can hit the sweet spot one day, and miss it the next. They can even swing through it several times in a single day. For example, 'Happy Hour' can cover up a lot of handling deficiencies, because of the extra grip from the tyres. That's why some drivers look quick on the timesheets during the week but, when it comes to qualifying, they're nowhere. They may have been running 'Happy Hour' every night..."

In 1994, both corner and lap speeds were generally higher relative to 1993, which was mainly a function of the cars having more downforce with a similar level of drag. Early in the month, there was a period in which the track itself also seemed to be quicker than at any time last year. With Ford XB cars, a lap average of 228mph was achievable, and

**Yellow Fever:** Pitstop action from Hall Racing as Teo Fabi heads for his seventh-place finish (top). The 941 takes both the Ilmor 265D (above, in the Hall team Reynard) and the Ford-Cosworth XB (right, in the Forsythe-Green car).







**Hemelgarn**  
 Racing's Reynard, driven by Stan Fox, was the newest 941 in the race. The pullrod/rocker arm front and rear suspension has received favourable comment from teams for the range and precision of its adjustability.

226-227mph was commonplace. In 1993, those speeds were generally only seen in 'Happy Hour' – the final hour of practice between 5 and 6pm, when some of the track is in shadow and the ambient temperature is dropping. That's when the Speedway gets fast.

At Indy, the speeds in the four turns are similar, because the corners themselves are similar. Any variations are due to factors such as wind and temperature, except that the car goes into Turns 1 and 3 at higher speeds. If the driver is going to lift at all, it will be going into 1 and/or 3. In the short chutes between 1 and 2 or 3 and 4, not enough speed is generated to require a lift.

The straightline speeds were similar to last year's although, because the cars were a little faster in the turns, they were also slightly quicker on the straights. An increase of 5mph in the turns is reckoned to result in a gain of 1-2mph at the end of the straights. The engines were also slightly more powerful than they were in 1993 – maybe a 2% increase.

The seven Reynards showed well during practice and, come the nerve- ▶





wracking qualifying days, all made the race. As Al Unser Jr claimed the pole for Penske at 228.011mph, Reynard's fastest qualifier was Villeneuve at 226.259mph, for fourth on the grid. The run by the Forsythe Green driver set new single-lap (227.061mph) and four-lap 'rookie' qualifying records.

Andretti was fifth fastest on 226.205mph, Fabi went 223.394, Gugelmin 223.104, Fox 222.867, Fernandez 222.657, and Vasser 222.262. Ostler commented afterwards, "We're disappointed in some ways. On our potential performance, we should have Vasser and Fabi on the second row, as well as Villeneuve. Fernandez could have been on the row behind. Gugelmin got himself on the bubble, and had to requalify the second weekend. It's just the way qualifying goes here: a few little problems with pop-off valves and the weather, and you end up on the eighth row of the grid. But generally I'm happy with the way our car has gone."

In the race, the Penske team had Ilmor's outstanding Mercedes 500I to power Unser Jr to the win. Relatively speaking, the teams with the latest Cosworth and Ilmor engines were evenly matched in terms of power. As ever, the success or failure of each team at the Speedway depended heavily on its race strategy, and the adaptability of its racecar.

"We adjust the setup during the race not so much to accommodate changes in the weather, which are unlikely to be

sufficient to make a real difference, but to allow for the track surface degrading as more rubber goes down," observed Robertson. "If raceday here is hot, more rubber goes down, and the track will change a lot during the race: we'll be dialling-in the car at each pitstop to chase the track conditions. That's done with adjustments to the front and rear wings, and with tyre pressures and staggers. All the teams have a range of tyres ready to go, of varying staggers.

"We can change ride heights under yellows but, because you don't want to lose too much track position, you won't do that unless there's a big advantage to be gained. The target is to keep up with the track conditions, staying on the pace and making sure you have a good car at the end. With the current track configuration, the winner will be the driver with the best car in the best track position after the last yellow. It's no good having the world's best racecar at the start, and letting its setup go off before the end..."

Early in the race, the Reynard that was engineered by Robertson offered clearly the strongest challenge to the Penskes of Emerson Fittipaldi and Unser Jr, but Andretti punctured a tyre on accident debris, and lost a lap in the pitstop when his engine stalled. Even so, the Target car seemed to have third place locked up until Michael was penalised a lap for overtaking under yellow. He was classified sixth.

For Hall Racing, Fabi soon ran into problems with a turbocharger which

Sidepod vortex generators on the Hemelgarn

Reynard (top left). Ganassi was one of the Reynard teams running a fin on the top of the engine cover (above left) along with the standard body kit, including this extension ahead of the rear wheel (top right). Jimmy Vasser's Hayhoe team Reynard finished fourth (above).

reduced his boost pressure from the optimum 45in to about 43in. His Pennzoil car finished seventh.

Gugelmin, in his first race on a superspeedway, ran steadily to finish in 11th place, using steel brake discs (rather than carbon) due to cost considerations.

The Hemelgarn car was brand new, delivered at the Speedway only 36 hours before qualifying. Fox also used steel discs, after a carbon disc had delaminated on Carburetion Day. He worked his way up to ninth by lap 180 but, due to a puncture, he hit the wall in Turn 1 on lap 197, causing the yellow under which the race finished.

Fernandez also punctured a tyre. Trying to make it back to the pits, he damaged the Galles car's suspension, and spun out in Turn 3.

The Consec STP car driven by Vasser ran consistently in the top 10 from the lap 25 onwards. His fourth place finish came after an extra pitstop to remove debris from a sidepod.

Very much the star of Reynard's show was Villeneuve. Apart from the Mercedes-Benz 500I engine, in fact, the French-Canadian rookie was the star of the motor race. He actually led for seven laps, albeit as a result of the pitstop sequences. Although he too stalled in pit-lane, and twice fell off the lead lap, he hung on grimly to the charging Penskes and, after Fittipaldi's crash, brought home his Players car in second place, solidly back on the lead lap. The Rookie of the Year was the most mag-



THE REYNARD 941 is generally a very safe racecar. The rear is quite stable: that's very important on any racecar, because you can then work on it to get the front progressively better. That's a great characteristic for ovals.

"I don't know about the other cars, because this is my first year in Indycars, but we can make changes on the Reynard and really feel the differences. That makes it a great car to work on.

"I don't like to have the car begin to turn in as I lift: a car that turns itself is generally oversteering a little. The front is quite heavy and I prefer it that way. It doesn't want to turn in by itself. I have to turn it and I tend to be smoother that way. For qualifying, though, I had a car that was neutrally balanced, or just on the edge of being loose. For the race, we dialed in a little understeer. But this is my first time here, so I might think differently in the future.

The ride quality is OK, but Turns 3 and 4 are quite bumpy. We run the car quite stiff and I do feel any bumps, mostly on the front. I don't feel the strip of bricks at the startline at 230mph but, in 3 and 4, the bumps feel like big waves.

The quality of the mechanical grip is difficult to judge here, with the little wings we use. It also depends on setup: I'm sure some Reynards have better mechanical grip, others better aerodynamic grip. On the first day you have it; a racecar can be good or it can be bad, so that you have to work to get it better. If it's basically a bad car, it will take much longer to get it better. The Reynard was a great car out of the box.

Turn-in is not really an issue here at Indy; you hardly steer into the corners. On other tracks, turn-in has been quite good but, at Long Beach, I had a terrible setup which gave me a hard time turning in and getting the rear stable to exit the corners. On street courses, usually the front understeers a little on turn-in, but the car is new and we still have a lot of suspensions to try.

The Reynard is very stable in a straight line, even in crosswinds. We're running a tail fin. When I tried it on the car, it felt little different, but I was quicker. We're not sure why; several people have tried it and had a hard time figuring out if it was better. I don't really notice any difference, but my feeling is that it adds a little stability in the corners. If you go a little sideways, the fin probably helps you to catch it. It might not make you faster, but I have the feeling that it might be safer.

The Reynard's handling does change as the fuel load drops. At the start of the race, or after refuelling, your speeds are reduced by the heavy fuel load, which causes a lot of understeer. From then, it depends how you use your tyres. If you use them well, the speed will remain the same or get better. At Long Beach, when I had a full tank, I was maybe two- or three-tenths off my fastest lap. When I started on a full tank, the pit out-lap and the first two or three flying laps were great but, after that, because of our bad setup, the car started to feel bad. It really does all depend on the setup.

"Compared with the Atlantic cars I've driven, the Reynard is a heavy car, and that's a good thing. You really have to be on the edge of the perfect setup, so that you can use the tyres better. The work you do is more important than on a lighter car. I do feel the weight when I turn in, but it's not a heavy car to drive. If we have a good setup, it feels great.

The basic setup is very important and that's put on the car before it leaves the shop. When we get to a race, we're just fine-tuning. The car is very sensitive to changes, especially on a speedway. Here tiny things make a big difference: on slower courses,

## FROM THE COCKPIT JACQUES VILLENEUVE



not so much. At Indy, you feel the effect of changes to the setup for mechanical grip more than the effect of wing adjustments.

"The gearshift is good. The sequential shift is an advantage because you can't go into the wrong gear, but it takes a while to get used to it. You have to pull the gear and lift—different to what I've been used to. Downshifting is often not fast enough: you have to push down the lever and wait until it comes back to push it down again. So on some tracks it's marginal in downshifting, but I think it's good for upshifting, quite fast. There is one problem with sequential: say something breaks and you want to switch off the engine, and you're in fifth gear and you want to go to neutral—you can't do that.

"I don't ever use the clutch for gearshifts because I left-foot brake. The braking efficiency is good, especially at high speed when you get all the effect of the downforce combined with the braking. With the speeds we go and the size of the brakes, it's easy to run into problems but, once I get them working nicely, the brakes are good.

"The cockpit is comfortable. I personally have one problem: I sit quite low, and sometimes I hit my elbows on the side of the monocoque because it's built up higher than I'm used to. When I tighten my belts really tight, I have a hard time to turn sometimes because my elbows get locked there. But in my experience, the cockpit is never perfect, whatever the car. Maybe I'm just sitting too low but, because of that, I don't have any problems with wind buffeting. I'm not using weird-looking helmets or anything. It gets hot in the cockpit sometimes, but I don't think about it until there's a yellow. While I'm pushing, I don't notice it.

"I don't like the new pop-off valve. I think it's difficult to figure out. You don't have the tube into your helmet, like with the old valve, so you don't hear it starting to open. There is a light on the dash to tell you when it's open-

ing. When it opens, the pressure doesn't drop a lot, you still have fairly good boost. That gets confusing, because you're not sure if the valve is open. When that happens, the boost is not constant: you often lose half an inch of pressure just because there are spikes in the system. Sometimes, it doesn't open when it should, and then it will start to open but won't close again when you lift. Sometimes, it feels as if it doesn't close completely and it's leaking. It's difficult to figure out where it's at. I liked the old valve much better...

"I was running wide-open for my qualifying laps. We had worked out a good setup for the qualifying run: I knew I just had to keep it floored, and that's what I did. I trusted the racecar, I didn't lift, and it worked out fine.

"I started the race conservatively, just trying to stay on the pace. I had some problems with understeer in traffic in the early laps but, as the fuel load dropped, I started to get oversteer. A few times the car even got a little sideways, but I managed to hold it. At the first stop, I got delayed in pit road by other cars, and then lost more time because I stalled the engine.

"On the second tank of fuel, I had even more understeer because of the condition of the track so, at the second pitstop, we put on more front and rear wing. The car felt much better and I was able to make up a lot of places.

"I tried to save fuel by getting a tow from the cars ahead whenever I could. I knew that the only way I could get near the Penskes was by making fewer pitstops. At the end of the race, we were nearly 10sec quicker on time spent in the pits than any other team.

"That strategy might have worked if Al Unser Jr had been forced to make a splash'n'dash under green. Because of Stan Fox's crash, the race finished under yellow, so we'll never know...



# Staying Power

As in the previous season, the fastest qualifier for the 1995 Indianapolis 500 was powered by a single-camshaft, pushrod, 3.43-litre engine, rather than one of the more numerous four-camshaft, 2.65-litre power units. But unlike in 1994, the pole position car, equipped this time with a Menard V6, could not maintain its performance advantage over 500 miles, and go on to win the race. Ford achieved a 1-2 with the XB engine, for Cosworth's first victory at the Speedway since 1987, while Mercedes-Benz retrieved third place with its Ilmor-made IC108. Both Ford and Mercedes, however, were very nearly eclipsed by Honda, with its brand new HRH four-cam V8...

By BRIAN LOVELL

In both 1994 and 1995, two of the three racecars on the front row of the Indianapolis 500 grid, including the pole car, were powered by 3.43-litre, single-camshaft-in-block, pushrod engines, with 55in mercury manifold pressure.

In 1994, the two Mercedes-Benz 500I engines of Al Unser Jr and Emerson Fittipaldi had been split by Raul Boesel's Lola, powered by a 2.65-litre, double-overhead-camshaft Ford XB engine, with 45in manifold pressure. Unser had won the race – the first time for a pushrod engine car – after his team mate had inexplicably hit the wall. Boesel had retired at half-distance, but the reputation of Ford's race engines had been retrieved by the fourth-place qualifier, Jacques Villeneuve's Reynard, which finished second.

In 1995, Scott Brayton started from pole position in a Lola chassis that had been tailored for the pushrod Buick V6 derived Menard engine. His similarly equipped team mate, Arie Luyendyk qualified second. Significantly, the front row was completed by a 2.65-litre, DOHC Honda HRH engine Reynard, driven by Scott Goodyear. Lola's Michael Andretti drove the fastest of the Ford XB chassis to fourth on the grid and Villeneuve, again driving a Reynard-Ford, qualified fifth.

But the Lola-Menards did not maintain their superiority through the race, as the leading pushrod engine cars had in 1994. They fell back due to problems with low boost pressure and fuel-feed, to finish seventh and 17th. Instead, Villeneuve achieved Ford's first Indianapolis win for the XB, and the first for Reynard.

However, Goodyear's Reynard-Honda was at or near the front for most of the race, and was all set to win for

the Japanese manufacturer when he was penalised for passing the pace car 10 laps from the end. Having ignored a black flag, Goodyear completed the race distance which, however wrong, served to prove the capability of the completely new Honda engine.

The Reynard-Ford combination, with Christian Fittipaldi, also took second place. The best-placed Mercedes engine car was the Lola of Bobby Rahal in third – a repeat of his 1994 performance after he had failed to qualify with the then ineffective, fledgling Honda HRX engine.

This overview must be postscripted with the reminder that the 1994 winning combination, Penske-Mercedes, had elected not to use its 'free-design' pushrod engines for a second time, because USAC had reduced its manifold pressure allowance to only 48in of mercury. Using its 'conventional' Mercedes IC108 engine, the team, surprisingly and uncharacteristically, failed to qualify either of its cars.

## Engine Rules & Performance

The intense Indycar rivalry between Cosworth Engineering and Ilmor Engineering over recent years has pushed the power output of a 1995-specification 2.65-litre engine to over 800bhp at some 13,000rpm. Honda has had to enter the contest at this performance level, but has now demonstrated its ability to succeed – after just one 'learning-curve' season.

For the engine suppliers, 300bhp/litre – over 300lb/sq.in (20.7bar) BMEP at maximum power, with 500-mile oval-track race durability – represents significant engineering achievement. It is shared by Allied Signal, which supplies its Garrett turbochargers to Penske, Honda, Menard and others, and by Holset, supplying Ford-Cosworth. These companies have continued to develop lightweight rac-

ing turbochargers with strictly regulated internal dimensions that have performance and durability commensurate with those of the engines themselves.

The figure of 300bhp/litre may not be remarkable in itself, but the DOHC engines are limited by regulation pop-off valve to 45in mercury absolute intake manifold (plenum chamber) pressure. This is only 7.4lb/sq.in (0.51bar) above the naturally aspirated level. When the turbocharged Formula 1 engines were in their final, most restricted phase, manifold pressure was still 64% higher than the present Indycar level.

A technical point here is that, in Indycar parlance, absolute intake manifold pressure – the total pressure seen by the engine – is called 'boost'. Many, in Britain at least, regard 'boost' as the compressor delivery pressure above the nominally atmospheric level, or 'gauge' pressure. So, to many, the boost pressure is not 45in of mercury but approximately 15in (7.4lb/sq.in – 0.51bar).

The 1994 contest at Indianapolis was not, however, primarily between 2.65-litre Cosworth and Ilmor engine racecars. Penske Racing had collaborated with Ilmor Engineering and its new shareholder, Mercedes-Benz, to field a completely new engine, designed to make best use of recently introduced relaxations to the 3.43-litre 'stock' engine category.

The Buick stockblock-based V6 has been campaigned at Indianapolis for a decade, being allowed 10in mercury higher intake manifold pressure than the 23% smaller swept-volume, DOHC engines – and thus, currently, 12.3lb/sq.in (0.85bar) above atmospheric pressure. The pole position capability of this type of engine has been demonstrated since 1992, but race reliability and success have remained elusive.

Since 1992, alongside the traditional Buick V6s, USAC has allowed virtually 'free-design' 3.43-litre pushrod engines (with a single camshaft in the block and only two valves per cylinder), with the extra 10in mercury manifold pressure. This option was not taken up by anyone in either 1992 or 1993. Roman Slobodskiy, of USA Race Cars Inc, had designed and prototyped a V8 'hemi' 3.43-litre full-race pushrod engine for Brayton Engineering by late 1993, but only the Ilmor-engineered Mercedes 500I has appeared. It was this

**"Indycar Engine People Do It The Hard Way would make an apt sticker legend. The pressure to contain costs has mandated engines of not more than eight cylinders, limited to ferrous connecting rods and mechanical springs"**



## ON TRACK

advanced, short-pushrod V8, with its hemi-derivative combustion chamber design, that enabled the Penske team to dominate both qualifying and the race in 1994.

American racing rarely allows a second chance for those who legally demonstrate generous alternatives in the rulebook...

Soon after the race, USAC made it known that the intake manifold pressure limit for the special single-cam engines would be reduced for 1995, from 55in to 52in mercury. This revision, effectively reducing potential power by some 5.5%, left the pushrod engines still viable. Accordingly, Ilmor had begun work on 1995 power units of this type for Penske when, in mid-August 1994, USAC announced a further reduction, to only 48in mercury – in the order of a 13% power reduction. This more severe limitation rendered the free-design pushrod category less advantageous, to the point where Ilmor designer Mario Illien decided to abandon it.

With hindsight, the Penske team would probably have had less difficulty, in qualifying for the 1995 race, with the near 900bhp that Ilmor could have pro-

vided from a revised 500I engine running at 48in manifold pressure.

Thus, at Indianapolis 1995, the only significant pushrod engine was Menard's stockblock-based V6, which retained (but in the race failed to realise) the full 55in manifold pressure allowance.

It was thought that the 1995 race would represent the last chance for these alternative-category, pushrod engines to compete. However, the Indy Racing League (IRL) proposals to do away with equivalency formulae, and adopt only unrestricted-design, 2.2-litre race engines, are yet to be implemented.

Thus it seems that the *status quo* may be maintained until after 1996 – albeit probably with lowered manifold pressure levels across the board.

In terms of the race engines at Indianapolis 1995, one of the undoubted stars of the show was the brand new DOHC Honda V8, which should have won its debut race. This engine is a genuine American-Japanese project.

Honda Performance Development (HPD), a subsidiary of American Honda Motor, was established in April 1993 as

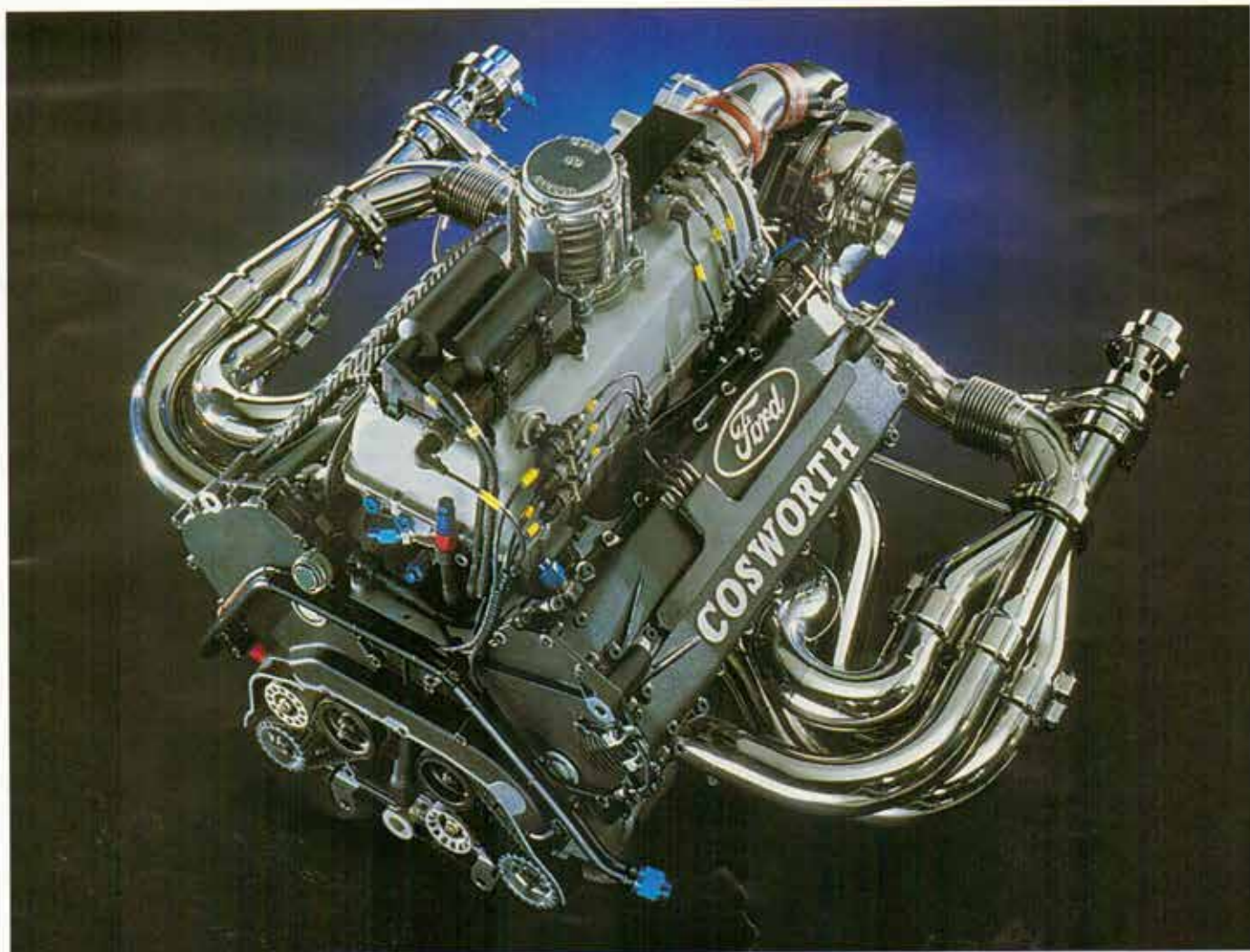
**"It is now clear to all that, as history has shown many times before, Honda has learned fast"**

a technical operations centre for the Indycar engine programme. HPD coordinates American Honda participation in the PPG IndyCar World Series. It is located at Santa Clarita, California, about 30 miles north of Los Angeles. Staffed by about 25 people, HPD operates out of a 43,500sq.ft (4040sq.m) facility housing race engine preparation, rebuilding and testing. Engine design, development and manufacture is in the hands of a 50-strong Indycar project team at the Honda R&D base at Wacko, in Japan. As many other engineer-specialists are available there to assist in specific areas of technology.

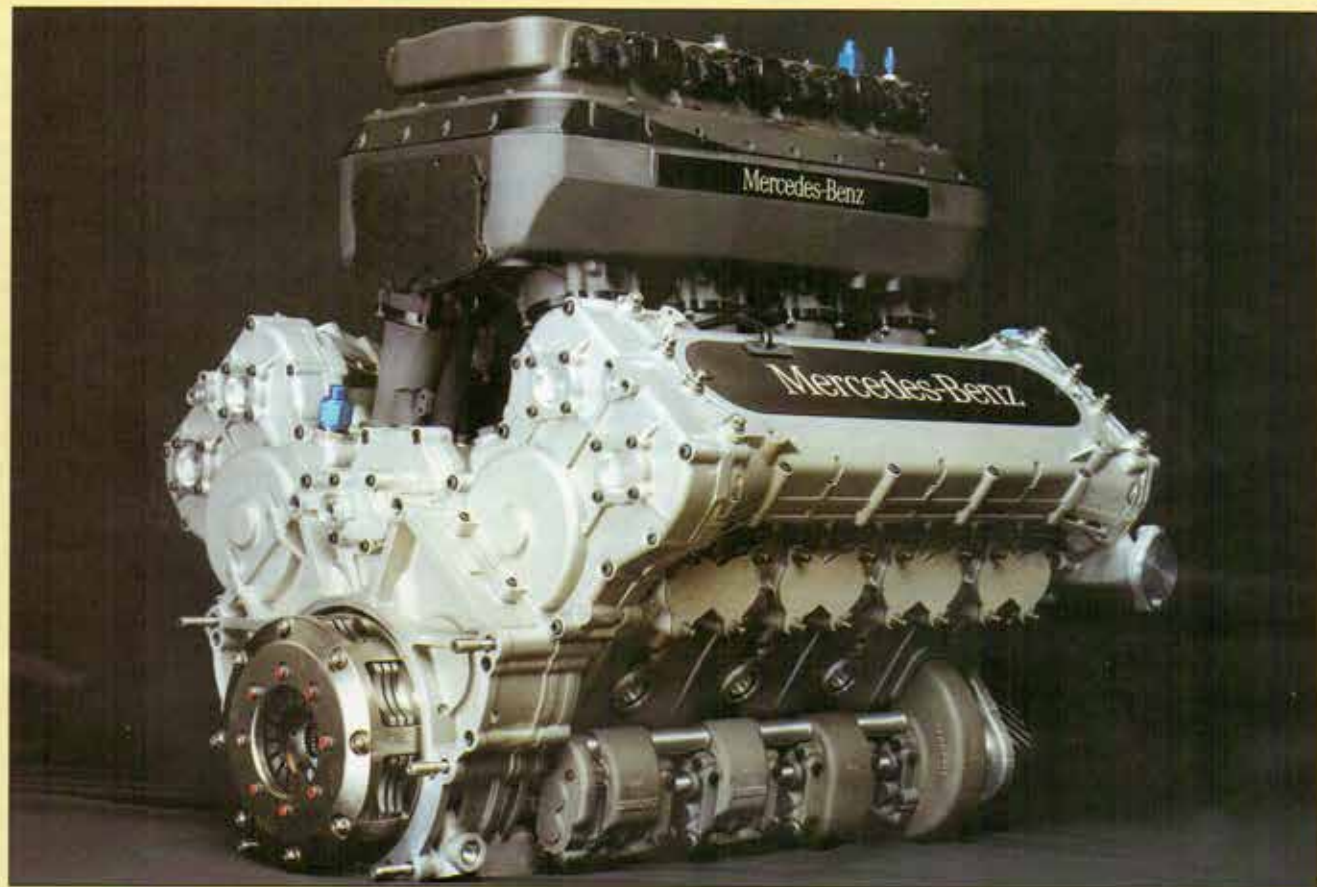
"Indycar Engine People Do It The Hard Way" would make an apt rear window sticker legend. The pressure to contain racing costs, where most of the teams are the customers of engine and chassis suppliers, has mandated engines of not more than eight cylinders, limited to ferrous connecting rods and mechanical valve-springs.

Pure methanol is the only fuel allowed, the bad news being that intercoolers are not – which limits compression ratio to approximately 11.0:1. Also, the fuel allowance for the race is an ungenerous (for methanol) 1.8 miles/US gallon – approximately 2.2mpg Imperial.

In the back of Jacques Villeneuve's Reynard, the latest 2.65-litre DOHC Ford XB engine brought Cosworth its first Indianapolis victory in eight years.







Mercedes-Benz, the 1994 winner, finished third in 1995 with Ilmor's updated 2.65-litre IC108 engine, powering Bobby Rahal's Lola.

THE CRUCIAL difference in USAC's regulations for the Indianapolis 500 lies in the inlet manifold pressures that are permitted for the various types of turbocharged engines. While the 2.65-litre, 32-valve V8 race engines were restricted, as normal, to 45in mercury of inlet manifold pressure, the genuine 3.43-litre, two-valve-per-cylinder 'stock-block' engines, like the Buick based Menard V6, benefitted from 55in of 'boost' (against the Indycar series limit of 50in). Purpose-built 3.43-litre pushrod engines were restricted in 1995 to 48in of boost, instead of 55in the previous year – which is why the 1994-winning Mercedes-Benz 500I did not defend its title.

Of the 33 racecars which started the 1995 race, 30 were powered by 2.65-litre DOHC engines. There were 23 equipped with Cosworth's Ford XB engine, five with Ilmor's Mercedes IC108, and two with the debutant Honda HRH. The other three cars were fitted with the latest Menard engine, a 3.43-litre V6 based on a stockblock Buick.

### Ford versus Mercedes

At Indianapolis in 1994, when 20 cars had been powered by the XB, victory had still eluded Ford, but Raul Boesel (Lola) had qualified second, Jacques Villeneuve (Reynard) had finished second after qualifying fourth, and there had been three others in the top six at the chequer. Typical maximum engine speeds had been 13,300rpm in qualifying and 12,800rpm in the race.

New evolutionary specifications of the XB, Series I and Series II, were in 1995 Indycar race use prior to Indianapolis. Series I includes revisions to the valve train and auxiliary drive, to improve durability. Series II covers, additionally, inlet tract revisions, within new cylinder heads, and fuel-injection system changes, to improve power.

A 500-mile test of the Series II engine, scheduled for the end of March, had to be cancelled

because of a shortage of the new components. Consequently it was considered unwise to use this relatively new engine build for the Indianapolis race. At first sight, the Series II version would have made a useful qualifying engine, but USAC ruled that the teams must race with fundamentally the same power unit as employed in qualifying. Because the proven Series I engine did not carry the new-design cylinder heads, the teams could not revert to it if they qualified with the Series II.

Prior to 1995, the last Indianapolis win by Cosworth had been in 1987, with the DFX. Villeneuve's victory and Christian Fittipaldi's second place underlined the capability of Cosworth and Ford. Three more XB engines finished fourth, fifth and sixth.

In 1995, Mercedes-benz had to be content with third place. After USAC's late rebuff of the 7in mercury cut in the manifold pressure allowance for free-design pushrod engines, Ilmor and Penske might have decided to design and build special-purpose 2.65-litre DOHC engines for Indianapolis 1995. However, there were other considerations.

Although existing DOHC engines could readily be downsized for the supposedly forthcoming 2.2-litre engine requirement, Ilmor and Mercedes had committed substantial efforts to a completely new 2.2-litre design, as well as the necessary new tooling for this. Then the clash with CART interests, disagreements over proposed IRL chassis regulations, and management changes at IRL all combined to slow down the IRL programme.

With such uncertainty about the implementation of the 2.2-litre engine rules, Ilmor and Mercedes put their new project on hold – after some 85% of the design work had been completed. Thus, the 1995 Mercedes IC108 Indycar engines were evolved from the 'Ilmor Indy V8' DOHC unit of 1994. This latter engine had been allowed 13,600rpm plus in qualifying in 1994, and 13,500rpm in the race – in which Bobby Rahal's

Penske-Ilmor PC22 had finished third.

Ilmor increased both the BMEP at high speed and the RPM capability of the 1995 Mercedes engine. For Indianapolis, an engine build with slightly more top-end power bias can be utilised, and this should have resulted in well over 800bhp being available in qualifying with, presumably, close on a safe 14,000rpm if required. Ilmor is reticent about revealing its piston cooling strategy, where oil squirt jets – favoured by Cosworth – provide a thermal safety factor at some loss of BMEP.

The Indycar races this year, prior to the Indianapolis, showed the Lola, Penske and Reynard chassis very evenly matched – and apparently the Ford and Mercedes engines. As has been freely admitted, however, the Penske chassis does have a fundamental problem with low cornering speed at the Indianapolis Motor Speedway – a problem which, in 1994, had been masked by the straight-line speed advantage conferred by the Mercedes 500I.

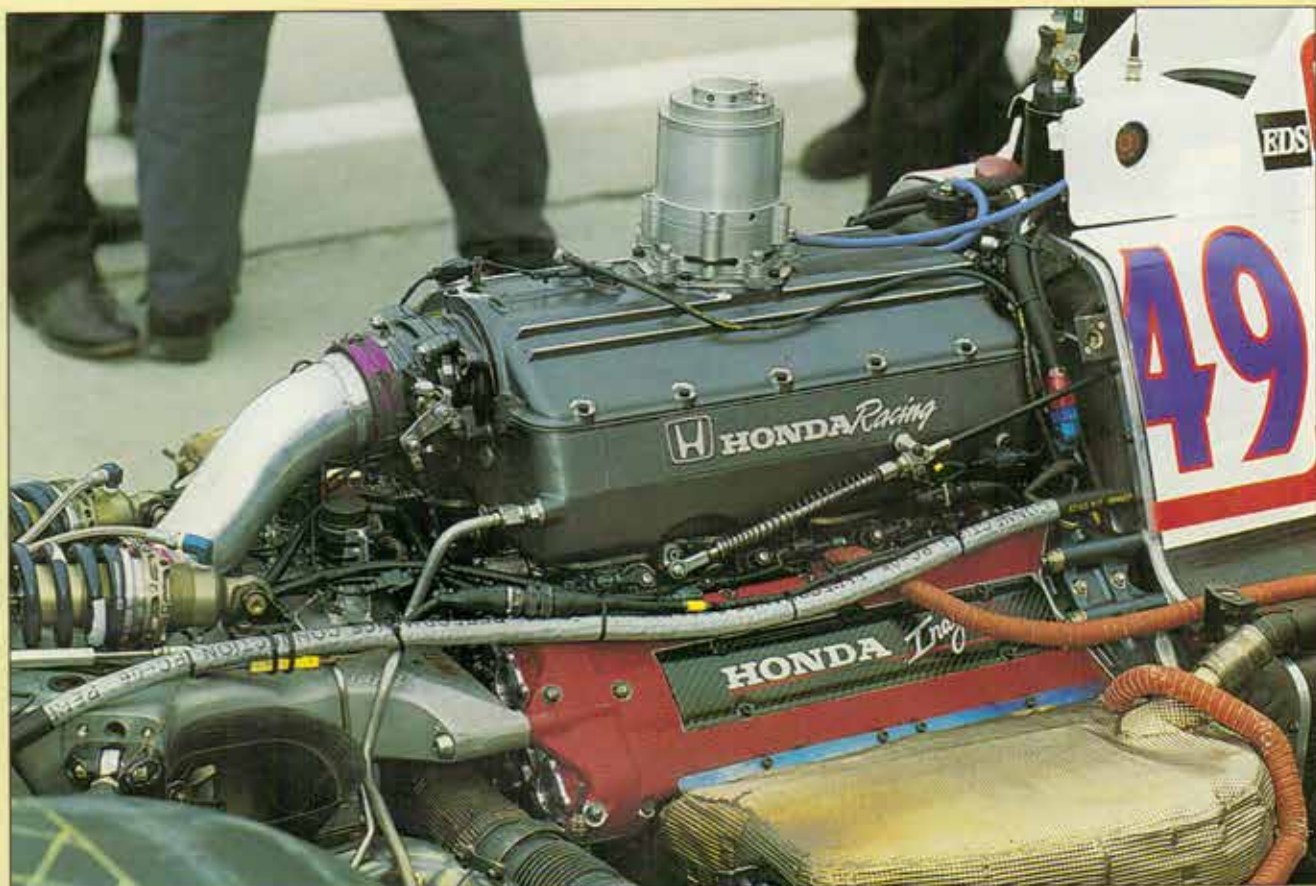
In May 1995, the potential of the Mercedes IC108 was not demonstrated in an optimised Penske chassis. Looking at single-lap performances in qualifying, Bobby Rahal was the quickest of the six Mercedes powered qualifiers, lapping his Lola at marginally over 230mph – 0.5mph slower than race winner Villeneuve's Reynard-Ford. However, Lola-Ford driver Michael Andretti's best lap was at a remarkable 233.7mph.

In all, nine Ford powered cars were faster in qualifying than Rahal's Lola-Mercedes. Therefore it must be concluded that the Ford XB engine, at Series I evolution specification, showed a performance advantage over the Mercedes IC108 – and that its first Indianapolis win was well justified.

### Honda's Debutant V8

Honda could not in any way be classed among the 'big boys' at Indianapolis. It may have created more successful race engine designs than any





Honda chose the 1995 Indianapolis to debut its all-new 2.65-litre HRH power unit, with which Scott Goodyear's Reynard should have won the race.

other company but, for the second year, it appeared to be running merely a pilot operation – prior to the 500.

The first Honda Indycar engine, the HRX of 1994 was somewhat overweight and under-powered for oval circuits – to the point where the Lola-Hondas had been abandoned before the final week of Indianapolis qualifying. Honda began its 1995 programme by providing new Reynard 951 chassis, fitted with revised versions of the HRX, to the Tasman team. The promising rookie driver of this rookie team, Alex Ribeiro put in some encouraging drives before Indianapolis, including a sixth on the grid and 12th place in the race at Nazareth.

For Indianapolis, the experienced Scott Goodyear was co-opted. He drove the Tasman Reynard-Honda to third place on the grid, having lapped at 232.25mph. Ribeiro achieved a 230.14mph lap and qualified 12th, immediately ahead of the best-placed Mercedes engined car, the Reynard of Roberto Guerrero.

The transformation in Reynard-Honda pace and fortunes was not, however, solely due to driver ability. From the start of qualifying, the entirely new Honda HRH engine was in use. It is now clear to all that, as history has shown many times before, Honda has learned fast. It has applied its racing experiences and data, so hard-won in 1994, to produce a thoroughly competitive Indianapolis/Indycar engine, with the necessary durability.

The task of creating a viable Indycar engine proved taxing for Honda, as it would for any engineering team totally unversed in Indycar/Indianapolis engine design constraints, oval track racing, delayed-recovery pop-off valves, and so on. It took some time, for example, to understand the characteristics and effects of methanol fuel, to achieve a light yet durable steel connecting rod design, and to overcome overheating difficulties.

The original Honda HRX began its racing life

with a cast-iron cylinder block, and something of a weight penalty, after the original aluminium block design had shown weaknesses. Honda had used a cast-iron block for the very successful turbocharged 1.5-litre RA168E F1 engine of 1988, and the change to this material, for the Indy unit, was to save further development time. With no experience of single-plane crankshaft V8s, in the very high RPM context, Honda initially used the fundamentally balanced, passenger car style, two-plane crankshaft. But, at variance with normal usage of this pattern, it chose to employ an irregular firing sequence, with each cylinder on one bank firing concurrently with one on a different row of the opposite bank. This scheme had shown some merit in Grand Prix motorcycle race engines. In the Indycar engine context, the concept showed improved low-speed torque.

A single-plane crankshaft was introduced for the 1994 Detroit Indycar race and, as the season progressed, durability problems were overcome only at the expense of some further increase in weight. In 1994 form, the iron block engines, although not completely raceworthy, were subjected to much laboratory running, and the design turned out to be an asset for this purpose.

For the start of the 1995 season, the HRX engine appeared in considerably revised form. The iron block was retained, but there were new heads and a new plenum chamber. Many changes resulting from 1994 race experience and dynamometer work were incorporated.

In time for Indianapolis, the completely new, 'clean-sheet-of-paper' HRH engine was ready – although it had not previously been raced. This aluminium block engine encompasses much of the learning from intensive development of the HRX design, and many of its concepts, but has no components common with it.

The new engine is approximately 45lb (20kg) lighter. The bore, stroke and cylinder bank angle are different, but Honda declines to state these for

either engine. Both units have front-end camshaft drive trains and five main bearings.

The HRH, which has become the Indycar race unit since Indianapolis, uses a Garrett turbocharger and wastegates, a Honda/Motorola electronic engine management system, and electronically controlled Honda PGM-FI fuel-injection and distributorless CD1 ignition. The engine is said to have very high safe crankshaft speed capability: Honda admits to 14,000rpm. Maximum power is modestly stated as 'more than 780bhp at 13,000rpm.'

A decision on the sourcing of parts to build the new engines for Indianapolis had to be taken in late February/early March, at which time the Comptech (Honda testing) team could not confirm sufficient sponsorship to support its becoming a second Honda racing operation. Accordingly, 'only' 22 of the new engines have been produced. This inventory took into account eight engines per car for Indianapolis alone.

HPD is targetting to supply three to four teams and six or seven cars in 1996. By all reports, following the Indianapolis demonstration, sales resistance is not a problem!

Toyota is set to join CART and USAC racing in 1996, which will further add to the Japanese presence, and the variety of prime movers.

### Menard's Pole Position

Indianapolis-based Team Menard achieved its first goal of 1995, in taking pole position, but again failed to redeem the unfulfilled promise of a Buick-based engine first (or even high) placing. Nor, this year, was there a lack of base engine reliability, although pop-off valve and fuel pressure problems completely spoiled the performances of Scott Brayton and Arie Luyendyk in the race.

Since taking over Buick engine development and race preparation from Brayton Engineering, without any financial assistance from General Motors, Menard has modified and developed the





Team Menard, whose extensively developed stockblock Buick V6 now carries its name, secured a 1-2 in qualifying, with Scott Brayton on the pole.

power unit extensively – to the point where it justifiably calls the current assembly a Menard engine. In preparation for the 1995 Indianapolis, 12 people worked on engine improvements alone. Ten engines were specifically built for qualifying, and another eight for the race.

The main changes were to the valve train, the induction system, pistons and pumps. The valve train now uses lighter and stiffer components, which permits the use of 10,200rpm in qualifying. This crankshaft speed is above the maximum power RPM, at which 850bhp is claimed (surely very conservatively). Race power is held down to 830-835bhp at approximately 9500rpm. At best, this is only 82% of that available from the Mercedes 500l running only 300rpm (or 3%) faster.

These performance levels were enough for Brayton to post up a 234.7mph lap, and for Luyendyk to prove this no fluke with a 234.9mph the day after. These drivers subsequently achieved four-lap qualifying averages of 231.604 and 231.031mph respectively, narrowly missing out on Roberto Guerrero's 232.482mph track record qualifying speed, set with a Lola-Buick in 1992. To put the Lola-Menard qualifying speeds in context, third man Scott Goodyear (Reynard-Honda) recorded 230.759mph, and fourth-placed Michael Andretti (Lola-Ford) 229.294mph.

In both qualifying and the race, several drivers complained of reduced power, due to pop-off valve problems, resulting in lower than the permitted 'boost'. Menard, in particular, has stated that the USAC pop-off valves, set to its allocated limit of 55in mercury absolute, are not compatible with the Buick-based engine. This implies that either the pressure fluctuation signature in the plenum chamber, or some form of mechanical vibration, can excite the pop-off valve prematurely. Certainly, Buick-based engine operators seem to have had an unequal share of pop-off valve problems, going back, at least, to when

Brayton and Eddie Cheever were unable to qualify at the potential of their cars in 1994.

These pop-off valves are not solely maximum pressure limiting devices. A 55in valve will reduce plenum chamber pressure to approximately 52in mercury if the driver, using his cockpit wastegate remote control, exceeds the 55in level. Pressure will then remain at the lower 'penalty' level until the driver throttles back momentarily. If, for any reason, the pop-off valve repeatedly triggers, the driver is left substantially with 3in mercury less manifold pressure. Where the potential is 850bhp, this results in some 785bhp.

It is only fair to Menard to highlight the reasons for its modest engine power when compared with that of the purpose-designed Mercedes 500l which dominated Indianapolis in 1994. Ilmor and Mercedes, of course, invoked an existing option in the rulebook but, still observing every clause to the letter, they were able to produce an engine, producing 1020bhp at 9800rpm, that was neither externally larger nor heavier than a typical DOHC Indycar unit. The Buick engine, although shorter than the V8s, is some 100lb (45kg) heavier. With the relatively longer stroke, and 90deg bank angle, it is wider and its centre of gravity is higher.

The 835bhp maximum power rating in race mode (139.2bhp per cylinder) results in a 9.0% higher thermal loading than the 1020bhp of the Mercedes 500l, with its two additional cylinders (127.5bhp per cylinder). And Menard engine durability is further threatened, in spite of running 300rpm more slowly, because its 21% longer stroke results in 13.6% higher acceleration of an inevitably heavier piston.

Clearly, the 55in manifold pressure, 3.43-litre pushrod option does not automatically provide a significant power advantage. Many of the performance limitations still with the Buick-based engine were either absent or less severe in the 'free-design' pushrod category, as it existed from

1992 through the 1994 race. That said, Buick or its engine users could have produced a cylinder head with hemispherical combustion chambers – giving them much needed extra valve area.

The Buick 90deg V6 is a stock-related, pushrod engine with a 4.0in bore, a cast-iron block, and simple, in-line valves. It is an all-American product, save for the TAG Electronics engine management system. Team owner John Menard claims that it was a low-budget engine in the 1980s, made up of 'off-the-shelf' hot-rod parts. This is probably an over-simplification, not doing justice to work that GM engineers, McLaren Engines and Brayton Engineering put in over the years. Nonetheless, what is now the Menard engine is fundamentally limited by its six (rather than eight) cylinders, by its wedge-chamber cylinder heads with, inevitably, small valve areas, and by its relatively long pushrods. Also, valve area is further compromised by a stroke/bore ratio of 0.69 – compared with the value of 0.60 for the Mercedes 500l.

The six intake valves of the Menard, in fact, are only 0.013in (0.33mm) larger in diameter than the eight of the Mercedes 500l – leaving the Menard with a significant 24% less total area. Together with the lower race-level RPM, this will result in reduced air consumption (mass flow per unit time) for the stock-based engine. Further, its more basic combustion chamber shape probably reduces the overall thermal efficiency – because of both its lower useable compression ratio and burning efficiency. These latter deficiencies equate to higher specific air consumption (lower IHP per unit mass of air consumed) which is compounded by the already-stated reduced air consumption.

Perhaps USAC was not unfair in finally reducing the manifold pressure for 'free-design' pushrod engines to 48in, but its engineers could have better foreseen their potential on 55in mercury...



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# Indy Infiniti



By BRIAN LOVELL

**N**issan is the second major automobile manufacturer to back the Indy Racing League (IRL) and its naturally aspirated 4-litre engine formula, which is effective from 1997. And because the cutoff date for OEMs to announce their intentions for 1997 has now passed, Nissan has become the only alternative engine supplier to Oldsmobile (whose Aurora V8 was fully described in *Racecar* V5N6) until after the Indianapolis 500 event next year.

At the Indianapolis Motor Speedway, on 14 February 1996, Jerry Florence, the company's VP of Brand & Consumer Marketing, confirmed that Nissan Motor

Corporation USA will compete in the 1997 Indianapolis 500 as an engine supplier. A racing version of the 32-valve V8 engine of the Infiniti Q45 'Luxury Performance Sedan' is being designed and developed in a joint operation between the Motorsports Department of Nissan USA and the parent company's Motorsports Planning Section, KP2, at Yokosuka near Yokohama. The fully single-seater orientated engine will be known as the 'Infiniti Indy' VRH40DE.

A 4.5-litre V8 with aluminium cylinder block and heads, the VH45DE donor engine begins life with the maximum allowed 93mm (3.661in) cylinder bore diameter of the IRL rules. The standard stroke, of 82.7mm (3.256in), must

accordingly be reduced, to 73.5mm (2.894in), to keep the swept volume below 4.0-litres.

A separate, single-row chain drives each pair of camshafts of the Nissan engine directly from a sprocket on the crankshaft nose, and this feature must, in general terms, be retained in the race engine.

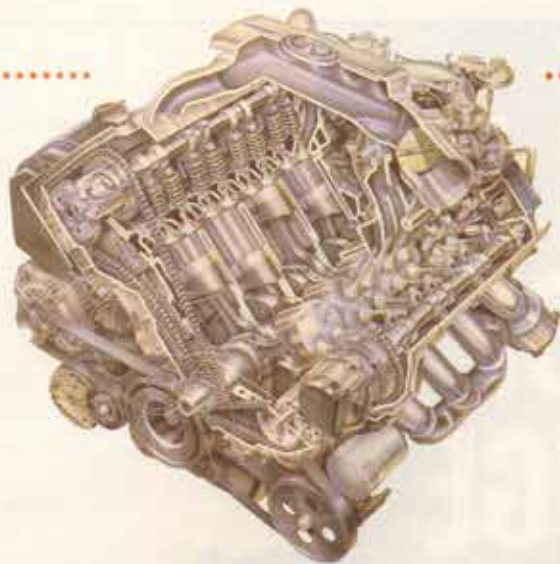
Although there are separate intake and exhaust camshafts in each cylinder head, the valve gear is of sophisticated, low-noise, low-friction rocker arm design. A needle-bearing roller on the top of each separate rocker interfaces with each cam lobe, and the pivoting ends of the rockers are located on hydraulically self-adjusting plungers. The inboard locations of these pivot units – either side of

the cylinder head centreline – preclude a narrow valve-included angle, but the IRL engine regulations do not require the retention of such production valve gear features.

A sophisticated variable valve timing system ('Nissan Valve-timing Control System') retards the intake camshaft 10deg at low speeds. However, even if Nissan wished to retain this feature – and could make it compatible with a 60% increase in operating RPM – it would probably be disallowed by the IRL, whose technical director is empowered to forbid any 'unfair advantage' technology.

The installed maximum power is 280ps (276bhp) at 6000rpm and the maximum torque 400Nm (295lb.ft) at 4000rpm.





Cutaway illustration of the Nissan Infiniti Q45 passenger car engine.

Competition versions of the Infiniti Q45 VH45DE power unit equipped the 1995 IMSA GTS-1 racing 300ZX cars, taking Nissan to three wins – including a third Sebring 12 Hours victory for the marque. But these 600bhp-plus, turbocharged, dry-sump engines retained the production cylinder block and heads. The production valvetrain as well, except for revised cam lobe profiles.

The design team at the Nissan KPI division in Japan, headed by engineer Taguchi (with local input from Nissan Motorsports USA under manager Frank Honsowetz) have the job of creating a completely new, 500-mile durability, full race engine. Under the IRL rules (see Taking Stock, page 19), only the cylinder spacing and the camshaft drive type of the base production engine have to be retained.

It is thus a 'clean-sheet-of-paper' (blank screen/new folder, perhaps, these days!) exercise – within the rules limiting minimum deck height and sump depth, and specifying a 90deg bank angle and crankshaft configuration, plus limitations on component materials.

The design of this 10,500rpm-limited, methanol-fuelled, 4.0-litre engine, nominally producing 650bhp, will incorporate direct-acting valve gear and a narrow valve-included angle. There can be no doubt that this task will be carried out meticulously, and that the subsequent development running will be thorough.

Previously known as 'KPA', the Nissan competition engine department has produced such successful and reliable engines as the twin-turbocharged 3.5-litre V8 'VRH35' power unit which equipped the R89 and R90 Group C sports-prototypes. It subsequently designed the 3.5-litre V12

'VRT' engine for World Sportscar Championship endurance racing, to take on Peugeot and Mercedes-Benz in this class until Nissan policy – and no doubt budgets – decided otherwise.

The difference from previous Nissan race engine projects, and this may apply to other IRL engine suppliers, is that the OEM does not have to supply complete engines. Nissan part-numbered cylinder-heads and blocks, for instance, must be made available to teams and engine builders. But the manufacture of these, and the provision of kits or parts, can be sub-contracted. Crankshafts, connecting rods, pistons, camshafts, valves and so on can be procured, it appears, from any vendor with which Nissan Motorsports USA is prepared to lodge drawings and specifications.

Nissan Motorsports will have developed a preferred engine build specification prior to Indianapolis 1997, through bench and track testing. Nevertheless, a race team's chosen engine builder may also have developed his own version of the Nissan race engine. Similarly, there may be several interpretations of the Oldsmobile 4.0-litre race engine, with differing power curve maxima and torque characteristics.

The collective effort which Frank Honsowetz's Nissan Motorsports team were coordinating at the time of writing included the IRL race series team Cunningham Racing (driver Johnny O'Connell), chassis designer Trevor Harris, and other consultants and designers.

The Indianapolis 500 may be somewhat devoid of technical interest in May 1996, but the 1997 event should herald new engine sounds, and new scope for both manufacturers and top engine builders to become involved.

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# Taking Stock

There is currently bitter rivalry between the new USAC-administered Indy Racing League (IRL), and the well-established Indycar World Series, run by Championship Auto Racing Teams (CART). Aside from the politics generated by that rivalry, the former's post-1996 engine rules are an event in themselves. For its own IRL series of races in 1997 – including, of course, the Indianapolis 500 – USAC has forsaken the *status quo*: the 2.65-litre turbocharged engine which has evolved over the past 20 years. In framing the IRL engine specification, USAC envisaged the participation of automobile manufacturers with 100% competition versions of current passenger car units, such as the Oldsmobile Aurora and Nissan Infiniti race engines.



Aurora at the Brickyard: A methanol burning version of Oldsmobile's Daytona winning 4-litre V8 will be built for the 1997 Indy Racing League in the first major commitment by an American automobile manufacturer.

By BRIAN LOVELL

The promoters of the new Indy Racing League were greatly encouraged in January 1996, when General Motors signalled its approval of the new IRL engine concept. The giant American corporation announced that it will celebrate the company's 100th anniversary in 1997 by competing at Indianapolis with an Oldsmobile Aurora V8 race engine (*Racecar V5N6*). What amounts to a second racing version of the 4.0-litre Aurora V8 will be designed and developed specifically for single-seater use in the 1997 Indy Racing League. Then, in mid-February, the Nissan Motor Corporation USA confirmed their participation at the 1997 Indianapolis event. This will follow a cooperative programme, between Nissan Motorsport USA and the Nissan competition engine design group, KP1, in Japan, to produce a single-seater race version of the (normally 4.5-litre) Infiniti V8 engine (page 16).

BMW, Ford have also shown interest in the IRL, each having been involved in discussions on the subject with USAC, but the cut-off date for manufacturers to announce their intentions to compete in the 1997 Indianapolis event has now passed.

The emphasis in the engine rules is largely on measures to hold down development, manufacturing and maintenance costs by outlawing design features and materials which would allow significant performance advantages for more heavily funded teams. At the same time, USAC will endeavour to maintain race engine equality between manufacturers by homologating only those designs and features which, in its view, are fairly within the intent of the regulations.

## IRL Engine Regulations

The 1997 Indy Racing League engine formula specifies production-based, naturally aspirated (NA) engines with a maximum swept volume of 4 litres (244cid), rev-limited to 10,500rpm. The IRL 'General Requirements' also call for engines of eight-cylinder, 90deg bank angle configuration, with cylinder bores of not more than 93mm (3.661in) diameter. Four camshafts and four-valves per cylinder are allowed. Two-stroke engines are not.

Overriding any race engine design that a manufacturer may wish to submit to the USAC Technical Director for homologation, the height of the cylinder block deck may not be less than 8.1in ▶





► (205.7mm), and the depth from the crankshaft centreline to the bottom of the sump no less than 4.5in (114.3mm). Production cylinder bore centre spacing must be retained, and a single spark-plug per cylinder is mandatory.

Cylinder head, block and sump material is limited to ferrous or aluminium alloys. Reciprocating valve train parts may be made from titanium, ferrous alloys or stainless steel. Valves must be returned by ferrous alloy coil springs. Crankshafts, connecting rods and wrist (gudgeon) pins must be made from ferrous alloys and, most importantly, single-plane crankshafts are outlawed.

The use of carbonfibre and ceramic materials is limited to non-stressed parts and thermal coatings respectively.

Crankshaft bearing positions and dimensions are 'free', but roller bearings may not be substituted for plain bearings. Camshaft drive systems must be as in the production engine – belt or chain drive being retained, for instance.

The 'small print' continues at some length, but the rules distill to describe race engines, designed by original

equipment car manufacturers (OEMs), based on a production engine utilised in a vehicle on sale to the public.

Qualifying production numbers will be judged, by USAC, on the basis of the manufacturer's normal levels: relatively few engines per year fitted to Ferrari road cars, many more to Oldsmobile models, for instance. All engine cylinder blocks and heads must be produced or sourced by the approved manufacturer, with part numbers and identification appearing clearly on the castings.

There is also a rule based on a concept that has worked well in other US track racing classes: "Eligible engine manufacturers must make available to any *bona fide* Indy Racing League team their approved engine (in either complete or kit form) at the price agreed by the manufacturer and the IRL." And manufacturers not supplying complete engines must designate a vendor(s) capable of producing the assembled product, at the cost agreed by the IRL, USAC and the manufacturer.

Engine builders and race teams, building up engines with approved

**The engines being used for the inaugural 1996 Indy Racing League are shared with CART's rival Indycar World Series or comply with USAC's 'stockblock' regulations, but it will all change in 1997.**

OEM-designed parts, may rework cylinder heads freely – provided that valve angles and the positions of all design elements are maintained. Valve spacing, intake and exhaust port centre-lines, and sparkplug and camshaft positions may not be changed.

The 10,500rpm rev-limiter unit will be provided and maintained by USAC, presumably in much the same way that pop-off valves are handled at the present.

Engine management systems, compatible with the USAC rev-limiter, must be submitted and defined to the IRL and USAC. In the same context, mechanical-only throttle control and non-variable exhaust and intake system lengths are stipulated.

Fuelling systems are limited to a single injection nozzle per cylinder. Methanol is retained as the only fuel allowed, with a designed power output 650bhp at the 10,500rpm limit. Finally, the target price for a complete engine is seen as \$75,000.

### IRL Engine Performance

With a stated aim of 650bhp, the 4.0-





## THE END OF THE TURBOCHARGED ENGINE ROUTE?

SUCCESSFUL though it has been over the last 20 years, the turbocharged 2.65-litre Indycar engine formula has long outrun the aims of its original concept. For it was conceived as a relatively inexpensive, off-the-shelf race engine, with a turbocharger installation provided by the engine builder.

The last 'buy an engine and turbocharge it' era came about when the American racers used destroked versions of the F1 Ford-Cosworth DFV. This action led swiftly to the dedicated Cosworth DFX Indy engine.

Nineteen years ago, there was no restriction on intake manifold pressure (although this was limited to 80in mercury (2.70bar) absolute for qualifying), and a DFX produced some 850bhp at 9500rpm. Thus, in providing some 50in (1.70bar) of supercharge pressure, the turbocharger was responsible for approximately 63% of the indicated power of the engine.

Currently, with manifold pressure limited to 45in mercury (1.52bar) absolute, 2.65-litre Indycar engines run at 50% higher RPM, and depend on the turbocharger for approximately 33% of their indicated power – this with considerably more sophisticated turbocharger, wastegate, intake, fuelling and boost control systems.

For the USAC-administered Indianapolis 500 until 1995, the teams had the option of using 3.43-litre (209.3cid), production-based, turbocharged race engines. These have not achieved their aim of a cheaper alternative power source. Such engines have required the aforementioned turbocharger-related systems to no lesser a degree. They have similarly suffered the ultra-high development costs attendant on 500-mile race durability from small-capacity forced-induction engines in general.

USAC's Indianapolis 500 engine rules have also included a 6.0-litre (366cid), naturally aspirated, camshaft-in-block, pushrod, two-valve per cylinder category. But this has not attracted any engine builder or race team interest – probably because of the sheer size and weight of such a power unit.

With no loss of performance, the costly 2.65-litre engine, with its turbocharger, wastegate 'plumbing' and control assemblies, could be replaced by a naturally aspirated engine having an additional 1.5-1.6 litres of cylinder swept volume. However, USAC has sought to impose both an engine speed limit (to reduce costs) and a substantial reduction in power.

This decision has enabled engine size to be held down to 4.0 litres, which is probably more attractive than a larger capacity to a wider spread of passenger car OEMs worldwide.

**“USAC has imposed both an engine speed limit and a substantial reduction in power, but future development will surely see the 4-litre, naturally aspirated, production-based IRL engine in the 700bhp bracket.”**

litre NA engine rules have been devised to allow some 200bhp less than the current 2.65-litre, turbocharged, full-race units that represent Ford, Honda, Mercedes-Benz and Toyota in the 1996 CART Indycar championship. The 1997 IRL engines will produce less power still than the 3.43-litre, pushrod, turbocharged, Buick-derived engines that have been sanctioned by USAC.

The NA engines should provide a broader band of near-constant torque, however, particularly in comparison with the delivery characteristic of the Buick engines with the turbocharger specification to which they have been limited.

Further, drivers pushing hard will be less troubled by the benign effect of the rev-limiter than the penalty of a triggered pop-off valve.

Reduced power is of little consequence in a race series restricted to a single engine type. But it is interesting to examine the performance potential of the new species of engines.

The chassis and car aerodynamics compatibility of the engines will not differ substantially between engine sup-

pliers and team to team, because of the mandated cylinder bank angle, and the rules specifying block height and sump depth minimum dimensions.

Here we have 4-litre 90deg V8 production-based – but also four-overhead-camshaft, 32-valve – engines. They will be essentially 'full-race' power units, because there is no requirement to apply the concessions and design constraints that are necessary in the production engine context, to suit passenger car conditions and regulations – fuel economy and exhaust emission controls.

Thus production intake system and cylinder head designs, for instance, can be replaced completely by concepts orientated only to performance.

For single-seat racecar use, of course, the engines will be designed as stressed chassis members, with appropriate, full load-carrying mounting bosses for the cylinder heads and crankcase.

The most restrictive of the engine rules are the RPM limit and the bore diameter limit, and the exclusion of single-plane crankshafts. For best performance, a cylinder bore diameter at the maximum allowed 93mm (3.661in) will be chosen – provided that the cylinder bore centre distance of the subject production engine is sufficient to allow this.

If the full 93mm bore diameter is employed, stroke becomes 73.5mm (2.894in), and mean piston speed at the limiting 10,500rpm is 25.73m/sec (5064ft/sec). At 0.79, the stroke:bore ratio is high in the context of modern pure race engines. But this is an advantage in terms of the achievable geometric compression ratio.

The most effective use of the anti-detonation properties of methanol should permit compression ratios in the order of 14.0:1.

With the intake valves sized towards

the practical limit (say, equal to 34% of the bore area), valve head based mean mixture velocity is 75.7m/sec (248ft/sec) at 10,500rpm. Such a value is realised at peak power RPM in some intensively developed race engines, indicating that the USAC technical staff have selected a very realistic relationship between the RPM limit and maximum bore size.

On the basis of the higher volumetric and thermal efficiencies that are attendant on full utilisation of the properties of methanol, specific power should be some 7.0% higher than that of Formula 1 and Formula 3000 gasoline-fuelled engines, at similar crankshaft speeds. On the other hand, with single-plane crankshafts ruled out, exhaust system effectiveness will be diminished such that any methanol-related performance bonus is likely to be cancelled out.

At first sight, the USAC target of 650bhp from the new engines would seem a considerable underestimate. Bearing in mind the exhaust system restraint, however, the 200lb/sq.in (13.85bar) at 10,500rpm that this represents may turn out to be very realistic. It is perhaps more important that the highest possible power output is realised at lower than the limiting RPM. And a BMEP of 212lb/sq.in (14.5bar) for 650bhp at 10,000rpm may turn out to be a fairly taxing initial target for the IRL race engine engineers.

F3000 engines of 1995 were said to realise approaching 500bhp at 9000rpm, or 240lb/sq.in (16.57bar) BMEP. With this in mind, future development will surely see the IRL engines in the 700bhp bracket.

But it remains to be seen how many manufacturers will participate, and thus how much competitive pressure is exerted on the engine originators and builders, towards intensive engine performance development. ■





# His Royal Highness

Honda's Japanese-American race engine became the prince of the Indycar power units in 1996, its third season of competition in the premier US single-seater series. Indeed the Honda HRH-A V8 power unit, currently designed and built in Japan, operated and funded in California, produced statistics reminiscent of the company's glory days in Formula 1. It won 11 victories from 16 rounds of the CART PPG Indycar World Series, including four in the Team Ganassi Reynard raced by the ultimate champion, Jimmy Vasser. Yet these results have merely strengthened Honda's racing resolve in the USA, to which country much of the technical responsibility for the project is now to be transferred.

By ALAN LIS

**T**hroughout 1996, just two seasons after a fraught introduction to the Indycar scene, Honda Performance Development ruled the roost with its HRH Indy V8 engine, which was employed by four teams – Brix-Competch, Ganassi, Hall and Tasman – operating six racecars. During the season, the all-aluminium HRH-A won 11 races, powering Jimmy Vasser to the

Drivers championship and the Target Ganassi organisation to the Teams title. Of the six Honda powered drivers running in 1996, five won at least one race, and the driver that didn't had a second place.

Honda's original intention had been to race an aluminium alloy block engine from the start of its Indycar programme, but the first such engine proved to be disappointing

under test conditions. With time running out, Honda fell back on technology with which it was already well-versed from Formula 1, and produced a cast-iron block V8.

That Honda HRX engine, which was raced throughout 1994 by Rahal-Hogan Racing, also utilised a two-plane crankshaft configured to provide a so-called 'big bang' firing pattern, as used in contemporary Honda Grand Prix motor-

cycle engines. Its application in Indycar was intended to reduce the inherent vibration associated with a V8 engine. However, it was found that driveability was compromised, and a single-plane crankshaft was used in later versions to alter the firing in an effort to improve torque characteristics. Before the end of the 1994 season, which included an embarrassing failure to



Andre Ribeiro's Tasman Lola T96 Honda won at Rio de Janeiro and Michigan.



Team mate Adrian Fernandez won in Vancouver.



# INSIGHT

qualify for the Indianapolis 500, the partnership with Rahal-Hogan had been terminated, and work was already in hand on the new aluminium block engine.

Raced for the first time at the 1995 Indianapolis 500, the aluminium alloy HRH was a clean-sheet (or blank CAD screen) design weighing approximately 35lb (16kg) less than the cast-iron block HRX unit of 1994. Like the HRX, the HRH layout utilised camshafts driven by gear trains taking their power from the front end of the crankshaft. The crankshaft itself was in nitrided forged steel, running in five plain main bearings. The bore and stroke of the HRH were altered from those employed in the iron-block HRX engine, as was the cylinder bank angle. Like many of their other features, however, these dimensions for both engines remain undisclosed.

Garrett AiResearch turbochargers were selected, in conjunction with a Honda/Motorola engine management system. In addition to controlling the Honda PGM-FI electronic fuel-injection and distributorless ignition, the EMS also controlled the turbocharger wastegates.

Apart from being substantially lighter in weight than the HRX, the HRH of 1995 incorporated many lessons that had been hard-learned in 1994, particularly in the optimisation of the mandatory methanol fuel supply. The HRH was also the highest-revving engine on the Indycar scene, and was thought to run up to 14,500rpm – perhaps 1000rpm faster than the rival Ford XB. On the race debut of the HRH, Honda's representative team, Tasman Motorsports came close to victory at the Brickyard, and eventually won a first Indycar race for the Japanese manufacturer later in 1995 in New Hampshire.

The 1996 engine has been known in factory parlance as the HRH-A, being a direct evolution of the original HRH. Externally, the engine appears much the same, although the plenum chamber has a slightly different shape, and there are other minor external detail changes. Internally, on the other hand, virtually every component is said to

have undergone some sort of change since the start of the season, some more extensively than others.

Like any race engine manufacturer, Honda's development programme concentrates on making the engine more fuel-efficient, on reducing friction and overall weight, and producing more power. HPD's general manager, Robert Clarke commented, "There are no startling new technologies – the CART engine rules are quite restrictive. I wouldn't describe the work we have done as anything out of the ordinary. You see it often in restricted series, such as Indycar, where you really try to reduce bearing sizes and surface areas to the absolute minimum. We are still using what are basically plain, shell-type bearings.

"It has really been a case of living with the engine and understanding it better. Finding where things can be reduced, or lightened, or changed in some way to make the package work a little better."

Honda's Indycar development programme has largely followed the style of its Formula 1 project, in that the engine specification has altered race-by-race. However, Clarke observed that, relative to the changes that HPD had been obliged to implement in 1994 and 1995, what was done during 1996 amounted to very small percentages. "The engine has improved race-by-race throughout the season. We might only be talking about only half a horsepower at a time, but it is an improvement nonetheless."

A major development step occurred at Road America in August 1996, when HPD introduced a further revised version of the engine incorporating a number of new ideas in friction reduction. Clarke: "It wasn't until the Road America race that we actually had enough confidence through dyno and track testing and having the opportunity to actually produce the parts in quantity to have them available for the race. They were what I would call high-risk components which reduced the weight of various parts and



Gil de Ferran's Hall Racing Reynard 96i won at Cleveland



Jimmy Vasser's Ganassi Reynard 96i won Honda its first Indycar title.

made changes to reduce the frictional losses. We wanted to make 100% sure that the product was durable. Our number one objective all along has been quality, which brings durability. Performance comes second. We are not willing to sacrifice durability to get a little more performance."

Since the beginning of winter testing prior to the 1996 season, HPD says that it has seen a 5% increase in peak power at the top of the RPM range, and an 4-5% increase in operating speed. The power band is also wider, and is said to be tuneable to the requirements of the circuit on which the engine is to be raced. Clarke: "I would say that our best power band for a road circuit situation is better than it has ever been before. Compromising the power band, we've also found ways of getting even stronger top-end power when we need it."

The significant peak power advantage that Honda enjoyed over its opposition at the start of

1996 had been reduced, if not eradicated, by the end of the season. At Homestead in February, the Honda engine, race trim, was thought to be producing 40-50bhp more than the rival Cosworth-Ford XD and Ilmor-Mercedes IC108, and as much as 100bhp more than the new Toyota V8. By the final round of the PPG Cup series at Laguna Seca, if there was any advantage at all, it was very slight over the Ilmor. Clarke: "I have a pretty good idea of where Ilmor are at, and they have made huge improvements. Of course, we don't know the actual numbers, but we do have an idea of their RPM range and they have made huge improvements. They should be complemented for what they have done."

"The Cosworth, I think, is capable of the same level of performance but, unfortunately, in 1996 they did not find reliability to go along with it. So excluding Toyota, I think the other three engine suppliers of



Parker Johnstone's Comptech Reynard finished second at Long Beach.





The Honda HRH V8 was Indycar's most successful engine in 1996, winning 11 of 16 races.

► 1996 were able to produce nearly equal power, at least for qualifying. For racing, I believe Cosworth has had to back off slightly. Ilmor also had to, for the first two-thirds of the season, but for the last three or four races they were able to maintain performance for the race.

A reduction in the inlet manifold pressure limit, from 45in to 40in, is to be introduced by CART for all races in 1997. This will affect the Honda engine in the

same way as its rivals. However, some evidence suggests that Honda may already have stolen a march. Clarke noted that HPD began development work around the 40in boost limit when it was announced that the teams would have to run to such a restriction, at Michigan back in 1995. Honda believes that it might have done its homework better than the others, since its engines have been significantly ahead of the opposition at each race held at the

superspeedway since then. Clarke: "I can only assume that our current edge comes from the R&D work that we've done around the 40in boost area. It looks like our induction system is working better than theirs at that boost level. Of course, we carried over the 1995 work along with some other investigation and development for the 1996 US 500 and Michigan 500, and again I think we proved ourselves to be stronger than the competition at both races. That

development is continuing. We knew back around early May that the 40in rule was coming for all races next year. So from that time we have been focusing more resources on development in that area.

"The 40in rule will change everything because it reduces peak power, and that necessarily affects nearly every component in the engine. Like the work we have done on optimising the bearings in 1996, we will be able to take a little more material off everything. Because of the lower power outputs, engine builders must reduce weight and friction again, to improve the efficiency and try to make up the deficit. Of course, as we find ways of increasing the power, we will have to start adding material again, but that's all part of the process. A race engine evolves continually."

A decrease in peak power of about 20bhp for every 'inch' of boost is anticipated. Consequently the engine manufacturers face the 1997 season with the prospect of a loss of approximately 100bhp. That represents a substantial, 12.5% reduction if the maximum output of a 1996 engine is assumed to have been 800bhp.

Clarke: "It's hard to say where everyone will emerge after the winter development period. That's the exciting part about this business - never knowing where your competition is going to be..." ■

## BACKGROUNDER: HONDA PERFORMANCE DEVELOPMENT

THE ORGANISATION at the core of Honda's successful Indycar race engine project, Honda Performance Development is a wholly owned subsidiary of the American Honda Company. However, it operates as a separate entity from factory and office facilities in Santa Clarita, California.

In a planned three-phase company development process, HPD is currently entering the second phase. The first was for HPD to establish itself as a service shop and a trackside support facility, to maintain and support Honda's competition operations in the USA. At present, all the design, development and manufacturing of components continues to be carried out in Tockigi, Japan.

The second phase of HPD's development is one of localisation, in which the majority of the engine components will be produced at HPD or sourced through local sub-contractors. The third phase will be for HPD to assume a portion of the development of the Indycar project.

Honda's Indycar engine design and engineering team is led by chief engineer Toru Ogawa. Ogawa is known in the Honda hierarchy as an "LPL" (Large Project Leader) and is in charge of the design and development of the engine in Japan. Ogawa has an extensive background in both Formula 1 and production car engines.

Kazutoshi Nishizawa is the chief engineer, with responsibility for trackside activities. He is the

head liaison engineer between HPD and Honda Japan and, during the racing season, works primarily in the USA.

David George and Steve Eriksen are HPD's key engine engineers. George has been with HPD since the start of the Indycar project in 1994, joining from Nissan Performance Technology Inc. Eriksen was recruited from Honda R&D North America.

For its increased involvement in the 1996 CART series, Honda was obliged to build no fewer than 80 examples of the HRH-A engine, allowing 8 for each car and a stock of dynamometer development engines. It was, according to Clarke, a "terrifying" commitment to make: "Going from 1995 with one and a half cars (the Comtech entry did not run all the races) to six cars in 1996 was a big step. Honda had never before done anything to that level of support, be it motorcycle racing, Formula 1 or Formula 2. We had never supported six cars at the same time before. At the start, there were anxious times, making sure that we had not only the people but the facilities, equipment and procedures to carry out such a programme. Our approach in 1994 and 1995 was very similar to what Honda used in Formula 1. The techniques used in building and maintaining the engines called for a very high degree of labour, checking and rechecking things. For our increased commitment, the approach had to be changed in order to adapt more of a production-

style assembly process."

To its factory staff at Santa Clarita and its trackside operation, HPD added 16 people, bringing the operation to a total of 52 including eight visiting Japanese staff. In addition, there are approximately 100 people working on the Indy project in Japan. Of those, around 50 are engineers directly involved with the engine.

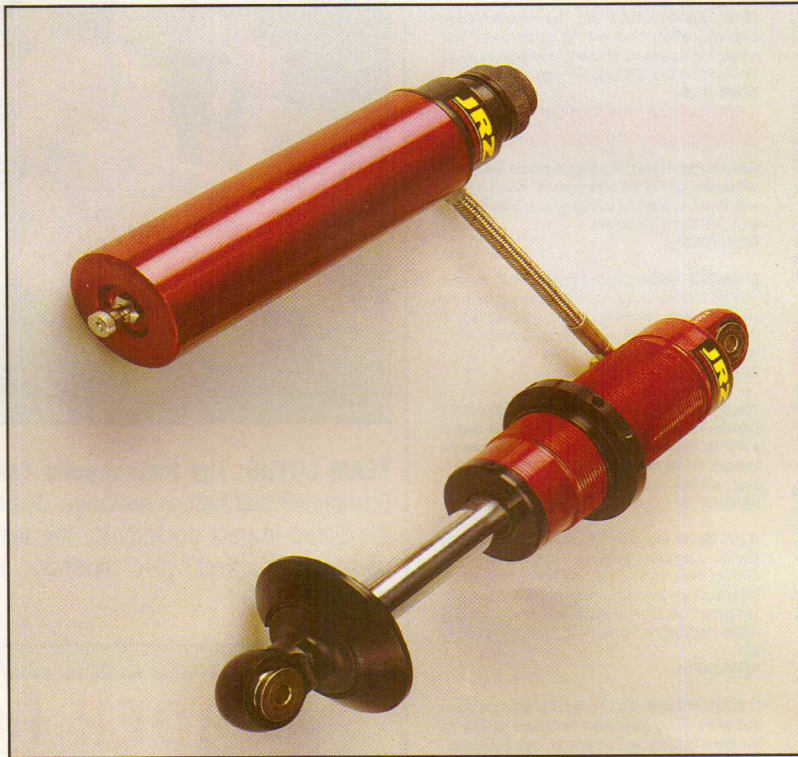
During Spring Training at Homestead in February 1996, according to Clarke, HPD received enquiries from six more teams regarding engine supply for 1997. However, further expansion of Honda's commitment will be limited: "It's difficult. We want to be a considered a major supplier in the Indycar series, but not to the level that maybe Cosworth was a few years ago. I don't see us going beyond 10 cars as an absolute maximum. I think we'd probably feel most comfortable with eight cars, which we would anticipate going to in 1998. Our capacity will allow up to 10, I think, but even that is a bit aggressive when there are four suppliers in the series."

"In 1996, we have been very fortunate. Things have gone extremely well. We have performed well, quality has been good, and we have met our objectives. But there were still some hiccoughs in how things were flowing and the support at the track was not quite at the level we wanted. For that reason, we made a decision that we would not increase the number of teams and cars we were supplying in 1997."





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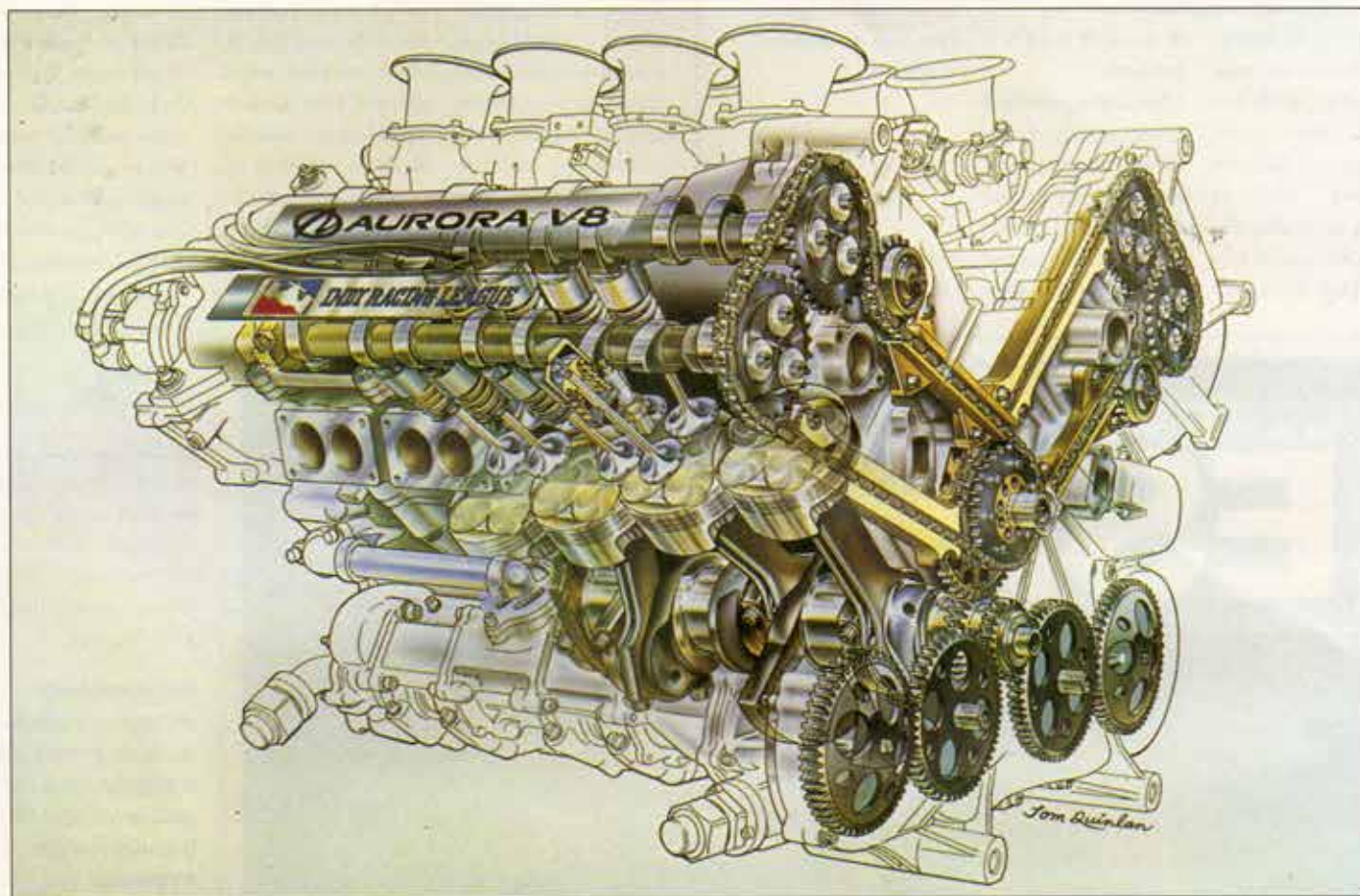


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By JURGEN STIFTSCHRAUBE

The 31st Louis Schwitzer Award was made in May 1997 to Ed Keating and Roger Allen of GM Motorsports, for their design of the Indy Aurora V8 engine. The award, which is made annually by the Indiana Section of the SAE in recognition of engineering excellence and innovation among the racecars contesting the Indianapolis 500, applauds their efforts in bringing a competitive race engine design to fruition, for over half the Indy Racing League field, in a compressed time period. Allen was responsible for the design of the engine, Keating for its development. Oldsmobile's IRL engine programme was approved on 4 January 1996, the first engine was run on 13 September 1996, and engines were provided for 16 cars at Orlando on 25 January 1997.

Both these engineers work for the GM Motorsports Group in Warren, Michigan. This is a highly focused enterprise group whose

# Lauding

responsibilities cover GM technical involvement in the Indy Racing League for Oldsmobile, in NASCAR for Chevrolet and Pontiac, in drag racing for Pontiac, and in SODA Truck racing for Chevrolet.

The roots of this IRL project date back to 1993-94, which was a difficult period for the Oldsmobile Division of General Motors, awash with rumours that it would cease to exist as a brand name. At this juncture, Oldsmobile pulled the Aurora passenger car forward a model year to promote a different divisional image.

Originally, the Oldsmobile brand had been targeted as a contender for the import market. The

new image was to target imported nameplates such as Lexus and Mercedes-Benz, and to develop sophisticated, multivalve powertrains. The motorsports image changed from that of the so-called Rocket V8, used in drag racing, to the all-new, high technology Aurora.

Oldsmobile had run a Cutlass with a 4.5-litre V8 in the IMSA GTS class in 1995 with Brix Racing, winning both the Manufacturers title and the Drivers championship (for Irv Hoerr). At the time of the creation of the Aurora V8, IMSA was the only venue which allowed multivalve DOHC engines. Having run the Cutlass in GTS, it was a logi-

cal step to use the same engine in an Aurora bodyshell.

In addition, IMSA was just launching its World Sports Car category. The rules for WSC engines were similar to those for GTS, and Oldsmobile took a 4.0-litre version of the Aurora engine to chassis builder Riley & Scott for its WSC racecar. In 1996, the combination won the Daytona 24-hour and the Sebring 12-hour races. Wayne Taylor won the WSC Drivers title, and Oldsmobile beat Ferrari for the Manufacturers championship.

Oldsmobile, however, was simultaneously having ongoing dialogue with the Indy Racing League and, in the spring of 1995,

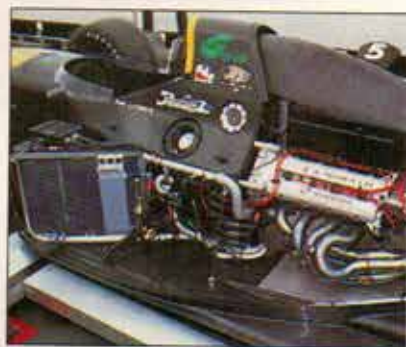




specific parameters for the formula were set by the IRL. The formula was to be less costly than purpose-built turbocharged engines, the engines were to develop less power, and the race-cars were to run at lower speeds. An initial committee consisting of BMW, Ford, Nissan and Oldsmobile met at the Indianapolis Motor Speedway in July 1995 to generate a formula. The engine configuration that was agreed upon was a 4.0-litre, dual overhead camshaft V8.

Oldsmobile's executives subsequently approved a race programme in the IRL, in which the company is currently competing only with Nissan. The objective for GM Motorsports was then to have 100 engine sets (50% of the field) ready for the 1997 Indianapolis 500. The plan called for providing engines for 13 cars for Orlando in January 1997 (which became 16), 19 for Phoenix in March 1997, and more

# Aurora



than 20 for Indianapolis in May 1997. At the time of writing, 104 engine kits had been built.

After the recipients of the 1997 Louis Schwitzer Award had been decided, the Oldsmobile Aurora engine exclusively powered the first five rows of the starting line-up at Indianapolis, where it was installed in 29 of the 35 chassis (83%) that qualified.

Having already been successful at Orlando and Phoenix, the engine went on to dominate the Indianapolis 500 itself when Arie Luyendyk's Treadway Racing team G Force (pictured at right) won from pole position. ▶



## OLDSMOBILE INDY AURORA V8 ENGINE PROJECT

AS OLDSMOBILE conceived the Indy Aurora V8 engine, its initial idea was to evolve the IMSA-style engine into an Indy power unit. But there were a number of problems to solve.

The IMSA engine was employed in touring cars (sedans) and the WSC sports-prototype, neither of which had the envelope restrictions found in open-wheel cars. The proposed rules for IRL stated that the engine must retain the cylinder deck height of the production engine. This is not a problem in touring cars, but was in a single-seater installation. It was decided, by the IRL rules committee, that a minimum dimension would be set at 205mm (8.1in), since it could be met by all of the engines under consideration.

The other architectural constraint was that the engines were to be confined to the production cylinder bore spacing. This was set at 102mm (4.00in) for the Aurora, with a maximum bore of 93mm (3.66in). The bore and deck height constraints caused an additional problem. The GTS car ran on 103-octane Exxon unleaded pump gasoline with a compression ratio of 12:1, but the methanol-fuelled IRL engine required both a much higher compression ratio (targeted at 15:1) and altered valve angles (in order to optimise thermal efficiency).

An IMSA engine was modified to run on methanol and evaluated. At this point, a decision was made to build a new engine specifically to run on methanol at the optimum compression ratio. This engine was to be Oldsmobile's first fully stressed engine. (The WSC engine was not a stressed member of the chassis, since there is ample width in the sports-prototype to support the back of the engine and the suspension).

The team at GM Motorsports decided that the weight of the engine and the package size would be reduced to provide the Aurora-equipped cars with the best possible competitive advantage. The engine came in very close to the estimated weight of 350lb (159kg) – approximately 60lb (27kg) less than the IMSA engine. (For comparison's sake, the dimensions of the Indy Aurora engine are very close to those of the original Ilmor Chevrolet and Cosworth DFX Indy engines).

One major hurdle for the project was that the WSC engine was a 'works' engine, with total builder control. It had no externally imposed cost ceiling, and a total build requirement of only 20

engines. On the other hand, the IRL engine would not be under total builder control. The IRL rules stated that it must be freely available, and in sufficient numbers to support 50% of the field in Orlando in February 1997. It also had to be designed to take full advantage within the rules from the start, since there would be no opportunity to build a second-generation engine.

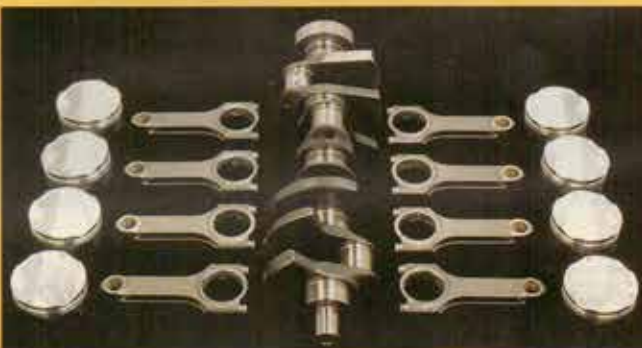
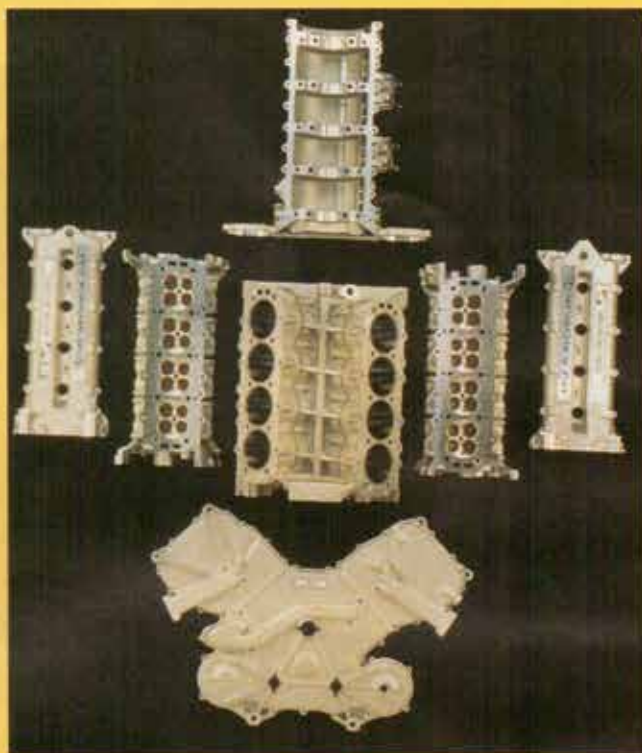
Because the IMSA engines had such a small build volume, the project could not support huge tooling costs with low amortisation. That engine used stock Cosworth 'low-line' pumps and similar bearing diameters and conrods to those of Small Block Chevrolet units, which enabled access to the huge inventory available in the USA.

The IRL project had a larger build plan and a projected model life of three years. Because of this, the GM Motorsports group was able to have its component suppliers (see separate panel) invest in the tooling for their respective components. Ed Keating is particularly proud of the organisation formed to build this engine.

The basic architecture of the engine was left to Roger Allen's group to define, the plan being for suppliers to participate in the design with responsibility for their individual components. In the beginning, there was a fear in the racing community that the new IRL formula would not be successful, and that participation in the IRL would compromise vendors who were also suppliers to CART. This was the cause of considerable tension – not a good thing on a project having such an aggressive schedule.

The intention of the GM Motorsports Group was to manage the design of the engine and the distribution of the block, sump, heads, as well as the front cover and the cam covers. It had no intention of being the distributor of all of the engine components. GM Motorsports assumed the risk of the long-lead items such as the crankshaft, and was also responsible for the development of the engine. However, the build of the engines was subcontracted to a core group of four companies, namely Katech (based in Mt Clemens, Michigan), Menard (Indianapolis, Indiana), Rocketsports (Lansing, Michigan) and Roush Engineering (Livonia, Michigan).

These four were responsible for the distribution of engine com-



Top: The cylinder block, heads and crankcase of Oldsmobile's 1997 Indy 500 winning Aurora V8 are cast by Zeus Aluminium Products. Above: The engine uses a BRE crankshaft, Carillo conrods and JE pistons. Right: The titanium valves are by Del West.



ponents. The rules state that the engines must be available from distributors for \$75,000. If a team desires modifications from the recommended design to its engines, it is free to do so at the market price.

Several other companies, including Brayton Engineering (of Coldwater, Michigan), Comptech (Eldorado, California), NAC (Chicago Ridge, Illinois) and Speedway Engine Development (Speedway, Indiana) perform assembly and some development in concert with the distribution partners.

Roger Allen's design group consisted of three contract draftsmen. This trio designed the basic outline scheme, and detailed the block, sump, heads and covers.

The detail design of other parts was done by the partners and transferred to the core group. All of the design was done on CAD, but only some was done in 3D – in which some of the partners and their vendors were not proficient.

The porting and combustion chambers were designed using CAD/CAM protocols. Most of the tooling was made using traditional pattern processes, in order both to take advantage of the expertise of the pattern-makers, and for speed – there were several problems with compatibility between drafting software.

The GM Motorsports group is able to call on the collective expertise within GM. As a result, engine simulation, cylinder pressure analysis using DSP, and



## THE LOUIS SCHWITZER AWARD

materials information came from within. The group has access to Ricardo's 'Wave' simulation, which was used to determine key tuning parameters for the Indy Aurora V8 project such as cam timing, valve events, inlet and exhaust systems, and so on.

Ed Keating led the engine development effort, in conjunction with three additional engineers within GM Motorsports. Development and the initial races uncovered some problems. Installation problems came from the design and execution of the racecar oil systems. Initial engine problems were experienced in the oil pump shaft details, the water pump drive arrangement, and the alternator vibration isolation. These were resolved by the first race at Orlando.

At Phoenix, there were seven engine failures. Five were due to the chassis oil system, the others due to an engine builder's change to a different piston. Execution of the design and construction of the engines for a mini-production run were some of the stiffest challenges faced by the group. Faced with the pressure of having the series riding on the ability of the group to deliver, the project group had carefully to evaluate all risks.

The timing of this enterprise was critical from the start. The Gantt chart indicated that tooling must start by 1 March 1996, and that an engine had to be running by mid-September. The crankshaft had a five-month lead, and had to be in procurement (for production) from the start of the project, along with other long-lead items like the block, heads and covers. The plan was to have engines for 13 cars at Orlando for the first race. In fact

there were engines for 16 cars (43 engines).

The first engines ran at low power level on Friday, 13 September 1996, at Katech. Oldsmobile shot a video on Saturday and, on Monday, it was given some throttle. The second full-dyno run produced the target power. A change in the inlet length was required to move the peak power point. No other changes were made.

After one day and five power runs, the first engine was disassembled and inspected. The number two prototype was being assembled concurrently for further testing. Four (of a planned five) engineering prototypes were built. Extensive durability testing simulating the Phoenix oval was done prior to the first car test. By late October, a race distance of 200 miles had been achieved on the dynamometer. On 13 November, the engine ran for the first time in a racecar.

As additional mileage was accumulated, the lower crankcase/sump was found to have a fatigue life less than desired. A casting revision provided significant improvement.

The engine was successful gaining pole positions and victories in the first two races, and repeated this feat at Indianapolis. Indianapolis presented different problems for the engine. At Phoenix, the rev-range is from 7500-10,200rpm, with the throttle being closed at the end of each straight. At Indy, the rev-range is from 9800-10,400rpm and the throttle is held wide open by most drivers.

The complete, assembled IRL engines were mandated to sell for \$75,000 each. The Aurora engine sells for \$70,000 as a kit.

THE LOUIS SCHWITZER Award, named after the eponymous US automotive pioneer, has been presented annually since his death in 1967 by the Indiana Section of the Society of Automotive Engineers (SAE). Schwitzer Inc continued the racing tradition of Louis Schwitzer by sponsoring the cash prize of \$5000 for the winners of the 1997 award. In addition, the names of the 1997 winners were added to a permanent trophy (displayed in the Indianapolis Motor Speedway's Hall of Fame Museum), and they received their award at a banquet in their honour in mid-May 1997.

The former winners of the Louis Schwitzer Award, which has been made to both chassis and component manufacturers participating in the Indianapolis 500, have included only six engines. The first was Dan Gurney's low-cost race engine in 1968, followed in 1973 by Smokey Yunick's stockblock engine, and four years later by the flat-eight designed by Bruce Crower and Bob Bubenik. Joe Negri and Ron Kociba received the award in 1985 for the Buick V6 Turbo engine, and Mario Illien has twice been the winner, in 1986 for the Ilmor Chevrolet 8, and in 1994 for the Mercedes-Benz 500i which won the Indy 500 on its only appearance (the latter accolade shared with Ilmor's co-founder, Paul Morgan).

Ed Keating is from Genesee, Michigan, and has a BSc in Mechanical Engineering. He worked for Buick Special Products from 1982-86, and was the program manager for the

Buick Indy V6 engine in 1985-86. He then joined Ford Electronics Division as a support engineer for the Benetton Formula team in Formula 1, serving the two seasons 1989-90. During 1991-93, he was the Program Manager for the Chevrolet Indy V8 project. Keating is the lead development engineer for the Indy Aurora V8 project and has always worked in motor racing, but for one of his years at Ford.

The lead design engineer on the Indy Aurora V8, Roger Allen is from Goodrich, Michigan and has a BSc in Mechanical Engineering from the Lawrence Institute of Technology. He worked at McLaren Engines while at college, then for Buick Special Products as a contract engineer from 1982-84. Since 1985, Allen has been a design engineer for GM Motorsports, having worked for McLaren Engines on the Buick V6 Turbo engine which won the 1985 Louis Schwitzer Award. He has designed cylinder heads for many GM racing programmes such as NASCAR, Busch, IMSA, WSC and GTS.

The 31st Louis Schwitzer Award Committee consisted of Bruce Watson (Cummins Advanced Engineering), Lee Fisher (Cummins Sports Marketing Manager), Pat Wildeman (Allison Transmission, Electric Propulsion Systems), Steve Holman (Program Engineer, Borg Warner Automotive Transmission Engineering), John Williams (Assistant Professor, Met Purdue) and Keith Pierson (Manager, Cooling Systems Engineering, Schwitzer Inc).

IN AREAS WHERE the normal expertise was not readily available in the USA, the GM Motorsport team resorted to sourcing from abroad.

The block, heads and crankcase are cast in sand by the UK company, Zeus Aluminium Products of Dudley, which also casts some parts at its facility in Pennsylvania. These parts were drawn on CATIA by Roger Allen's design group. This is the first thin-wall casting block used by Oldsmobile.

The pumps on the IMSA Aurora engine were stock

Cosworth 'low-line' pumps, but the IRL engine employs five-stage oil pumps specially designed by Geoff Goddard of TWR Engines. Both the pumps and the camshafts are manufactured in the UK by TWR Engines, which also supplies the camshaft tappets.

The cam drive assembly is from Cloyes-Renold, while the pistons, pins and rings are from JE Pistons.

The connecting rods are made in California by Carillo, but the valve springs are produced in Germany by Schmitthelm. The

crankshafts are made by BRE, whose Sonny Bryant manufactures many of the crankshafts for NASCAR.

The main and rod bearings are supplied by Vandervell. The titanium valves and retainers are supplied by Del West, while Brake Engineering supplies the water pump assembly.

The engine management system is what was the 'Gen IV', and is now known as 'DECISE', from Delco Electronics. Zytex provides the ignition/coil module, and the fuel system and injectors come from GM Motorsports out of the

AC Rochester division, which is now known as Delphi.

Kinsler provides the induction system. The WSC engine had a GMM-designed barrel mechanism, with four separate barrels, each with its own support bearings, to control inlet air. It was decided to use a simple and more cost-effective butterfly design for the IRL engine.

The wiring harness is from GM Motorsports out of the Packard Division of GM. The fuel system and ECM are similar to those components supplied for the Chevrolet Ilmor V8.







THIS IS A

# SPOILER?

By PAUL HANEY

In the 1997 CART ChampCar races at Michigan Speedway, west of Detroit, and at California Speedway, at Fontana in southern California, the racecars seemed dangerously fast. Scott Pruett earned the pole position at Michigan that July with an average speed of 233.857mph. Two months later, in the season-ending event at Fontana, Mauricio Gugelmin drove a world-record qualifying lap of 240.942mph. The series points leader, Alex Zanardi crashed twice. There were other terrifying crashes.

That was the inaugural event at the banked, 2-mile California Speedway, which was built as a copy of the Michigan Speedway by Penske Motorsports Inc, the company that also operates Nazareth Speedway and North Carolina Motor Speedway.

After the 1997 season, CART set a goal of reducing speeds at these two tracks by 20mph. That began months of discussion during

*All track racing series face a problem of increasing cornering and straight-line speeds, due to continuous improvements in racecar aerodynamics, engine power, and tyre performance. The risk of driver and spectator injury increases as speeds spiral upward. The reaction of CART, the sanctioning body of the US-based Fedex Championship Series, has been to introduce the so-called 'Handford Device' to replace the normal rear wing at the two super-speedways in the ChampCar schedule. In its first application in the US 500 in late July 1998, this device had an unexpected side-effect: it completely transformed the quality of the racing.*

which CART, working with the competing tyre companies (Bridgestone/Firestone Inc and Goodyear Tire & Rubber Co) and the engine constructors (Cosworth/Ford, Ilmor/Mercedes-Benz, Honda and Toyota) failed to come up with a universally acceptable speed-reducing rules package.

In response Mark Handford, the technical director of CART constructor Swift Engineering, designed a device to replace the rear wing that would lower the net aerodynamic downforce that is developed by the ChampCars, and increase aerodynamic drag to the extent that the drivers were unable to lap the entire



ChampCar team owner Derrick Walker had a hands-on involvement in the Handford Device, supplying cars for back-to-back testing at Fontana.



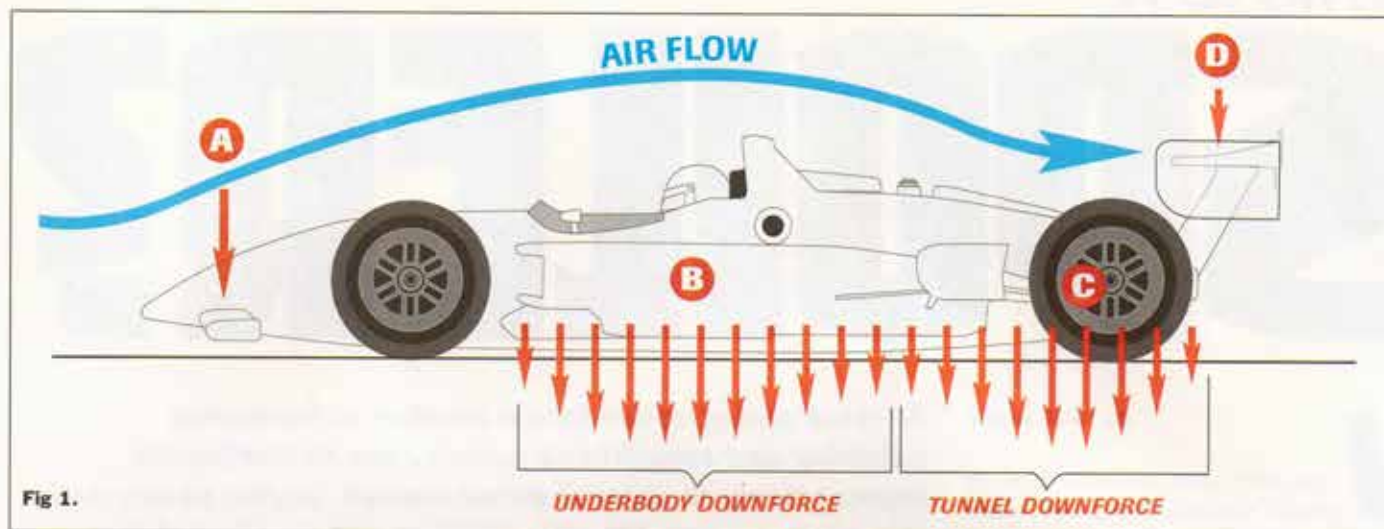


Fig 1.

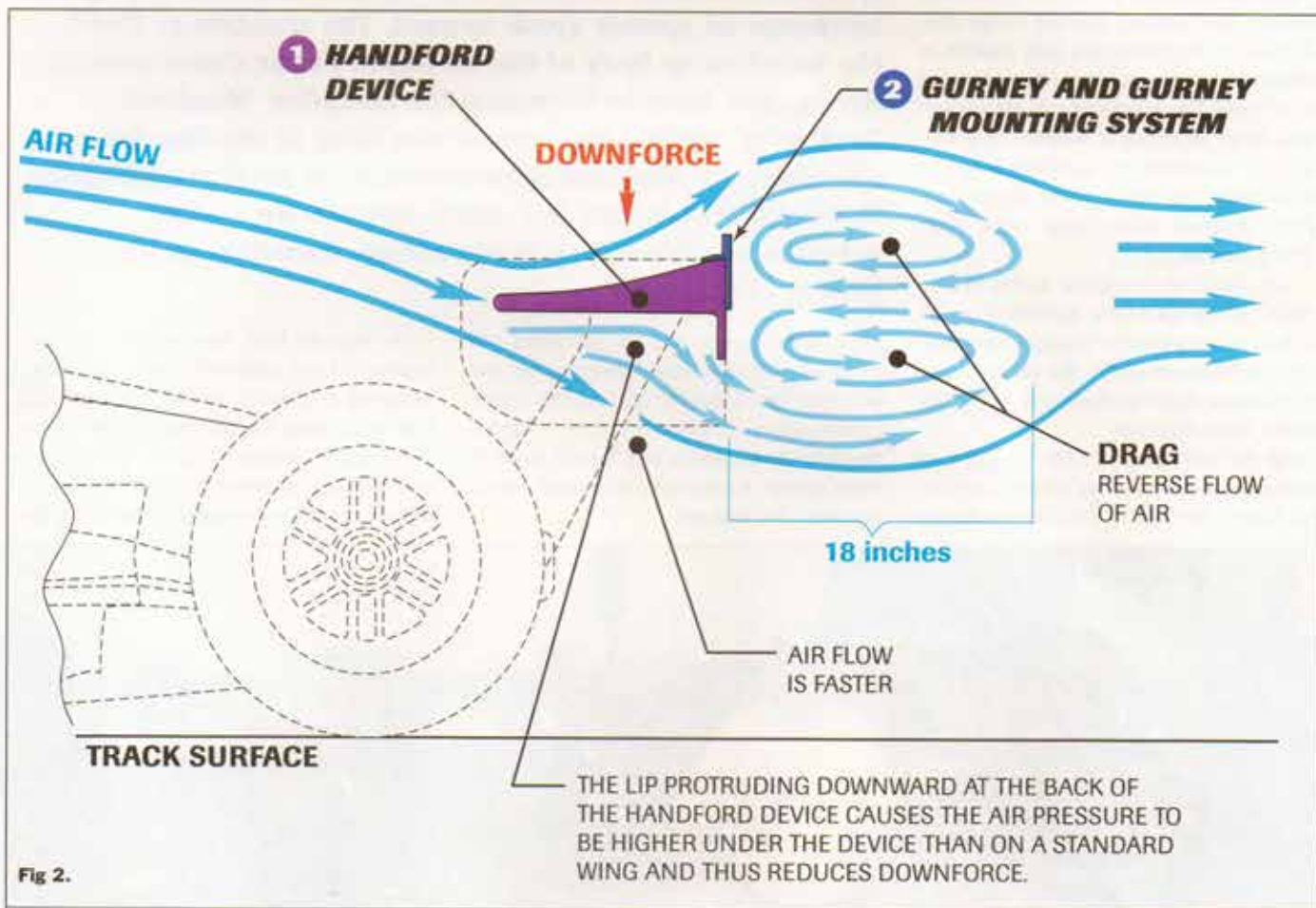


Fig 2.

superspeedway track at full throttle.

**Fig 1** shows that the nett downforce produced by a ChampCar – indeed any modern ground-effects car – is the sum of forces from the front wing (A), the underwing (B), and the rear wing (D). Constant improvements in tyre technology (C) also contribute to rapidly increasing cornering and straightaway speeds.

The height of the Handford Device (**Fig 2**) is 6in, with a chord of 14in, and its span is the same as the standard wing at 43in. In addition to the Handford Device, CART specifies three other rear wing configurations: road course, short oval, and speedway. This new device has become the specification at the two CART superspeedways.

The initial design had no 'Gurney' flap but, in testing at California Speedway in the spring of 1998, drivers complained of passing difficulties and instability in traffic. This test also revealed a balance problem, indicating that the aerodynamic centre of pressure had moved too far forward, tending the cars to oversteer. The chassis constructors conducted wind tunnel testing and devised in-fill parts for the existing underwings that improved aerodynamic balance and the overall performance of the underwing when used with the Handford Device. Modified front wings also helped to improve balance.

CART decided to allow a Gurney flap with a height of up to 1.5in, but most teams ran

a Gurney of 0.5in or less in the US 500 race at Michigan.

During qualifying, Adrian Fernandez earned pole position with an average speed of 229.519mph (only 4mph less than in 1997). This is a prime example of a performance-limiting rule negating progress by motorsport designers and engineers.

The 1998 US 500 provided three hours of intense, wheel-to-wheel racing – with more than 60 lead changes. This was one of the most exciting events in CART history. It demonstrated the desired effectiveness of the Handford Device, plus an added benefit: plentiful overtaking opportunities, due to the lower drag imposed on a car trailing another.



## INTERVIEW: MARK HANDFORD

THE CREATOR of the Handford Device, Dr Mark Handford is the British-born technical director of Swift Engineering, which operates from a 60,000sq.ft facility in San Clemente, California. Swift's capabilities include composite production and a state-of-the-art rolling-road wind tunnel which can run 40-50% models at speeds up to 140mph. The Williams and Stewart Formula 1 teams have utilized this wind tunnel, and the Swift ChampCars undergo constant development in this facility.

An employee of Newman-Haas Racing prior to his position at Swift, Handford received his Ph.D in aerodynamics from Imperial College, London and was responsible for the aerodynamics programme of the first Swift ChampCar (the 007i, first raced in 1997) and the 1998 version, the 009c. Handford also worked as an aerodynamicist for the Formula 1 teams of FORCE, Tyrrell and Benetton. He succeeded David Bruns as Swift's technical director earlier this year.

Contacted by telephone at Swift a few days into August 1998, Handford asked the writer to hold while he moved from the wind tunnel control room to a quieter office nearby so as to listen to the first question:

*How did the Handford Device get its name?*

My name got tacked on to it, but it wasn't a one-man show by a long shot. Reynard built test pieces with short lead time. Walker Racing tested the first version with an open mind, Kirk Russell at CART worked very hard with all the teams, and Todd Bowland at Newman-Haas did the simulation work. It was a collaborative effort.

*It seems the device has proved to be a somewhat controversial success after its first appearance in a race. The drivers were able to draft each other, and the racing was extremely exciting, but the spectator deaths and injuries (plus some post-race driver comments) clouded the issue.*

Yes. The device and the 'marbles' [tyre debris] are mentioned by some as the cause for the accident that resulted in the tragedy, but the marbles were a problem before. That issue is difficult to do something about. Journalists have written that lower downforce allowed the tyre companies to bring softer tyres to that race, which then produced even more marbles than usual, but I'm not sure that's true.

We set out with the honourable intent of making a rear wing that would develop more drag and less downforce. Previously drivers at Michigan and Fontana were able to lap the

entire track at full throttle. We thought that, if we lowered downforce and increased drag, we would force them to lift the throttle going into the turns and that would result in safer racing.

The drafting was an accident. I only heard two weeks before the race at Michigan that closing speeds were very high. That didn't occur to us before.

We knew that the device - it's not really a wing, so we called it a device, and then my name got stuck to it - would throw off a very dirty wake. But we underestimated the amount of reverse flow behind the car (Fig 3).

The air rushes in to fill the space behind the device, and some of that air is going in the same direction as the car, but at an even higher speed. The fact that there is very little vertical load on the device fortuitously results in negligible upwash of the wake. So the wave 'hangs around' in just the right place such that a following car runs into it with its device. The following car then experiences lower drag than would be the case if it wasn't in the wake."

*How did you come up with the design?*

First we thought we could design a rear wing that would produce some lift, lowering the net downforce of the car without increasing drag. Then we looked at estimates of engine, tyre, and chassis improvements for 1998, and realized that speeds at Fontana could go as high as 250mph.

The rules governing the CART underwing with a 6in high diffuser have been in effect since the 1996 season. There has been a 25% improvement in underwing performance since then, and yearly improvements are significant. Using 200mph as a sort of standard speed, we got around 5000lb (2270kg) of total downforce from a 1997 car in road-course configuration, and about 1700lb (770kg) pounds at Fontana. This is even with the blockers [inserted parts that block half the diffuser area specified for Michigan and Fontana] in place. We saw that could be looking at 2300lb at Fontana in 1998. So, instead of designing a low-drag, negative-downforce rear wing, we decided to increase drag also.

This is not just a safety issue. CART specifies the rear wing for the speedways, and the teams spend a lot of money on drag reduction programmes including significant wind-tunnel time. A high-drag, low-downforce rear wing might make those speedway-specific programmes less relevant than continuing to pursue downforce.

Todd Bowland helped with the detail goals. He used their mechanical simulation software to

look at a range of drag/downforce possibilities. We wanted the drivers to have to get off the throttle going into the corners, and come off the corners with about 100bhp surplus so that they could accelerate down the straights. Todd did a fair amount of work before we felt like we knew enough to make a wind-tunnel model. What we came up with was not exactly a wing, but a wing-like device. It was actually difficult to make it look like a wing. The 2in lip on the bottom at the trailing edge kills the downforce.

*What about the Gurney?*

That wasn't a part of the original design. During the early track tests, the lack of downforce at the rear wasn't balanced with proper front wings, and the resulting oversteer scared the drivers. There hadn't been time to make all the proper parts. That was unfortunate, because it created a loss of driver confidence. We had to convince them we could make it work. Kirk Russell worked very hard to hold the project together.

The Gurney was a last-minute modification to give the teams some adjustment. It added a lot of downforce. The goal was to make the drivers get off the throttle but, in qualifying, they were able to lap at Michigan near-flat. A half-inch tall Gurney added about 150lb of downforce (approximately 10% more) with little drag penalty.

*In the end, the pole qualifying speed only decreased 4mph.*

That's right. But without the device, the speed might have gone up to over 240mph. That is the problem with performance-limiting rules. It looked like a significant change in downforce and drag during wind-tunnel testing. It seems that, no matter what the performance reduction scheme is, the teams quickly get back two-thirds of the loss.

*Do you think you could tailor the Handford Device to work at other tracks?*

We can modify the device to generate more or less drag, and more or less lift. But you have to be careful.

It will work at tracks where the cars are in the same speed range in all corners. It might be a problem at Gateway [near St. Louis, Missouri] where you have one end of the oval slower than the other. Coming out of the slower corner, the cars would have more surplus power than at the faster corner, and the drivers might find it difficult to control power oversteer.

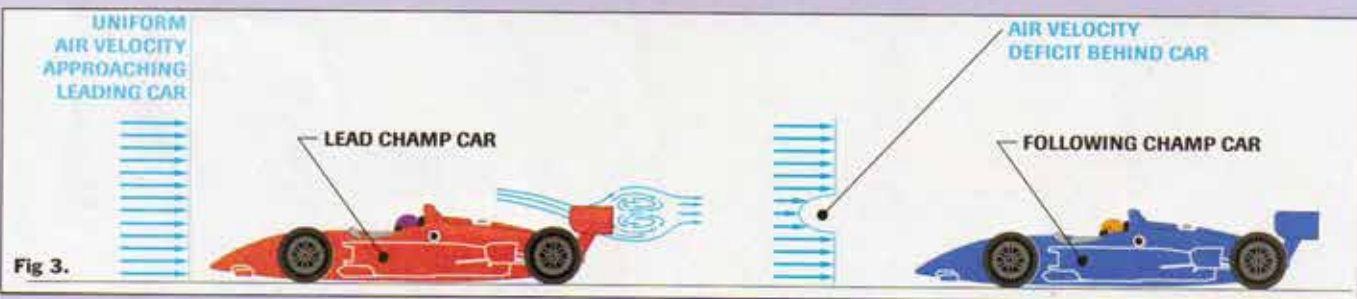


Fig 3.



► During the race, two drivers posted best laps averaging more than 228mph.

The event was marred, however, by the death of three fans (and injuries to six others) when a tyre and wheel assembly vaulted the safety fencing after a crash by Fernandez. Comments made by drivers after the race clouded the verdict on the Handford Device. Alex Zanardi described the race as: "Exciting but 'funny' – not really racing." Michael Andretti questioned if close racing was appropriate for open-wheel cars. Jimmy Vasser was quoted as saying that he was lucky not to crash himself, and that the accident had been due to a combination of loss of downforce and rubber debris caused by relatively 'soft' tyres.

Vasser's remarks echoed what many others have noted: the tyre war between Goodyear and Firestone has been resulted in soft tyres causing a thick accumulation of tyre debris, which has turned many circuits into one-groove tracks in the final stages of a race. The racing line remains relatively free of debris, but a driver finds a lack of grip when trying to pass off-line. The tyre engineers say they know no way to limit the debris thrown off by the tyres.

Due to the tragedy of the spectator deaths – the worst possible outcome of a racing event – many CART insiders did not want to be quoted. All the technical people contacted, however, had the opinion that the Handford Device was a step forward, and had not been to blame for the spectator deaths and injuries. The new rear wing will be used again at the California Speedway in November.

The rival Indy Racing League has taken a different approach to aerodynamics with its oval-only series. The IRL's answer is to limit engine power output by means of a tight

engine specification and an RPM limiter, while mandating flat-bottom racecars with a high-drag, high-downforce rear wing. To balance the cars, the teams have to run a high-drag front wing also. The result is low straightaway speeds but high cornering speeds – not the complete solution. IRL racing has been exciting, but crashes have destroyed many cars and injured a worrisome number of drivers.

NASCAR stock-car drivers are adept at racing single-file at high speeds, and then speeding up while in the leading car's wake, using the resulting momentum to help them overtake. That type of close, lead-swapping racing is the envy of top-level open-wheel racing: Formula 1, IRL, and CART. The top-level NASCAR Winston Cup race series enjoys full grandstands and earns TV ratings that are multiples of CART and IRL ratings.

NASCAR drivers are also used to a competitor interfering with their car's aerodynamics, causing a spin and possibly a crash. 'Taking the air off the spoiler' is a common event. A following driver noses the front of his car up under the spoiler on the rear deck of the car ahead, causing the air to leap directly from the top of the leading car to the top of the following car. The cars race on oval tracks very close to the limits of grip, and the loss of 30lb of force on the rear tyres can cause a spin.

CART drivers will now have to learn a new drafting/passing game, utilising the wake behind this new device. A leader cannot pull away after a pass because of the increased drag. A following car can attain a higher speed while experiencing low drag in the wake, utilising the resulting momentum to 'slingshot' around the leader. The passing car, however, can also 'destroy' some of the downforce of

the car being passed if the driver pulls in front of that car. The results can be dramatic if the cars are near the limit of grip. That seems to be what happened to Fernandez just before he crashed: Paul Tracy's car drafted past and drifted up in front of Fernandez, causing him to lose downforce, slide up the banking into the tyre debris, and hit the wall.

After the US 500, Steve Challis, engineer of the race-winning Reynard-Ilmor/Mercedes driven by Greg Moore, remarked: "I was one of the guys saying the Handford Device wouldn't work, but I was wrong. That was close, exciting racing, and the TV show was great for the fans. The tragedy in the grandstands was horrible, but that had nothing to do with the Handford Device. Qualifying speeds would have been over 240mph with the normal wing. I think they could come up with a different Handford-style rear wing for each of the really high-speed tracks, and create some great racing. We wouldn't win them all. We'd have to work at it like everybody else. We need to have a good show for the fans in the stands and on TV. I think the Handford Device will help."

Steve Conover, engineer of the fifth-place finishing Swift-Cosworth/Ford driven by Richie Hearn: "I was against the Handford Device before the race, but it was a great race and a great show. The drivers could run wheel to wheel and side to side. They had to be careful, but that's true in any race. The new device created an engineering challenge for us, but a good car was still good. The car responded to changes. Richie said the racing was fun."

Kirk Russell, CART's VP of Competition, said: "The Handford Device not only contains speed levels, but reduced them and provided exciting racing."





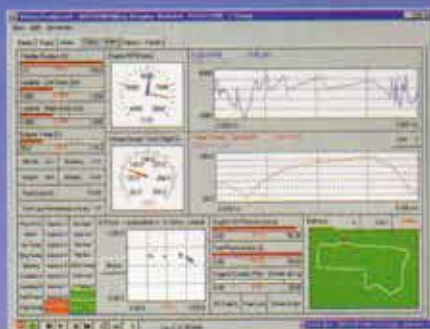
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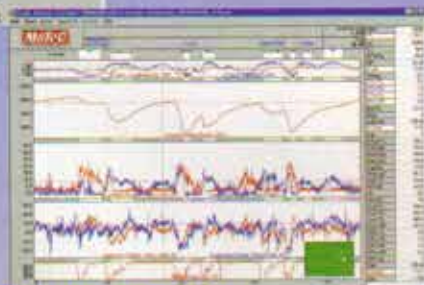
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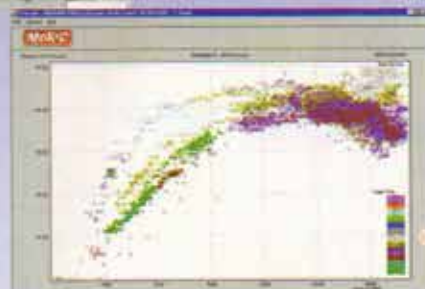
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# MoTeC

Engine Management & Data Logging Systems



By ALAN LIS

**T**he 1999 Fedex Series marks the 20th anniversary of the takeover of the USA's premier single-seater series by Championship Auto Racing Teams Inc, which had been formed for this purpose by the teams. They were dismayed by their lack of participation in decisions regarding regulations and administration taken by the previous sanctioning body, the United States Automobile Club. CART Inc was formed on 25 November 1978, and elected U.E. 'Pat' Patrick elected as its president, and a board of directors comprising Tyler Alexander, Bob Fletcher, A.J.Foyt, Jim Hall and Roger Penske. Of this group, only Patrick and Penske are currently active in CART competition.

Both CART and USAC staged IndyCar championships in 1979. In the CART series, Cosworth was the dominant engine supplier, its DFX powering virtually every runner. The rules limited inlet manifold pressure to 50Hg, and peak power outputs were in the region of 600bhp. UK-built Chaparral, McLaren and Penske chassis faced opposition from US-built Eagle, Lightning, Parnelli and Wildcat racecars. American drivers won every round, there being just one non-American competitor. All but one race of the 14 were run on ovals, all in the USA. Of these, only Michigan International Speedway is still on the calendar: the fastest qualifying speed there in 1979 was 204.001mph.

Two decades on, it is interesting to note both the differences and similarities in the current CART series, which has now evolved into a major international track racing championship.

In 1999, four automobile manufacturers are active in the championship: Ford (in partnership with Cosworth), Honda, Mercedes-Benz (in partnership with Ilmor), and Toyota. Turbocharger boost pressure is limited to 40Hg, but the peak power level is in the region of 850bhp. The products of five chassis builders are racing, the UK-based Lola, Penske and Reynard companies ranged against the US-based Eagle and Swift. On the 28-strong entry list for 1999, there are only seven American drivers. The series comprises 20 rounds, nine on ovals, six on street circuits, and five on road courses. Two events are staged in Canada, one in Australia, one in Brazil and one in Japan. The fastest qualifying speed at Michigan last season was 229.519mph.

In 1999, the CART rule makers continue to develop ways of restricting the performance of the cars and their engines. Chassis performance limitations are targeted at aerodynamic efficiency. The 'Handford Device', introduced in 1998, was successful in reducing speeds on Superspeedways, and coincidentally made for good racing, making it

a big hit with spectators if not the drivers. Now CART is looking to reduce performance on short oval tracks.

In 1998, the use of low aspect ratio front and rear wings became mandatory at ovals of more than 1-mile, such as Homestead and Gateway. For 1999, these wings are also required for the 1-mile ovals at Milwaukee and Nazareth, where the cars were previously allowed to run with high-downforce wings, similar to those used on road and street courses.

At the time of writing, the engine rules seemed likely to remain unchanged until 2001 at the earliest. The restrictions on turbocharging have made increases in RPM and mechanical efficiency the main avenues for improving performance. In 1999, crankshaft speeds of 16,000rpm and above are a target.

The UK constructor, Reynard Racing Cars is again the dominant force in the chassis market, although its share is slightly reduced, supplying its 1999 chassis to eight teams. The Californian constructor, Swift Engineering has four teams running its O10c, while UK builder Lola Cars International is supplying two teams. Both Eagle and Penske are represented by single cars.

Nine cars are powered by Cosworth's Ford engines, seven by Ilmor's Mercedes-Benz unit, seven with engines supplied by Honda Performance Development, and five with engines by Toyota Racing Developments.

The ChampCar transmission market is again divided between Hewland, which has projects with Swift and Lola, and Xtrac, which has projects with Penske and Reynard. Brembo's OEM supply of Eagle, Lola, Reynard and Swift means that the Italian company remains dominant in the supply of brake equipment. Alcon Components supplies Penske.

The damper market is again predominantly supplied by Ohlins, although Koni and Penske have minor representation, and a small number of teams have their own damper development programmes.

In the tyre war, Firestone may be on the brink of wiping out Goodyear from the ChampCar class. According to an unconfirmed rumour circulating at the 1999 Long Beach Grand Prix, Goodyear could become the exclusive supplier to the rival Indy Racing League in 2000, leaving Firestone as the sole supplier in the FedEx Championship Series.

**Pitstop during the 1999 Long Beach Grand Prix for Patrick Racing driver Adrian Fernandez's Ford XD powered Swift O10c.**





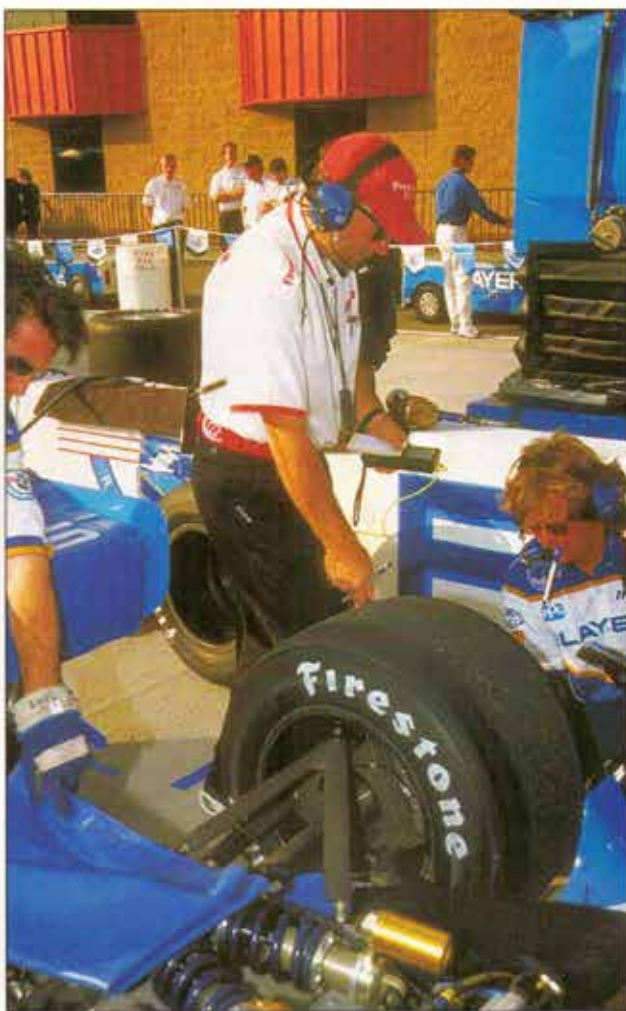




EVERYONE always seems to have assumed that the competition between the Goodyear Tire & Rubber Company and Bridgestone/Firestone Inc is an even battle that might swing one way or the other, but would never yield a clear winner. Maybe we were wrong!

Firestone and Goodyear began their competition in American racing – meaning the Indianapolis 500 – early in this century. Goodyear left racing in 1922 but began a new racing programme in 1963, winning the Indy 500 in 1967. Firestone succumbed to the attack and, after three straight Goodyear victories at Indy, retired from big-time racing in 1974. Goodyear went on to build a winning reputation in most of the top racing series in the world including Formula 1, CART and NASCAR.

Firestone was purchased by Bridgestone Corporation in 1988 and announced a return to racing in 1993. It



logged more than 12,000 miles testing tyres the following year, and resumed head-to-head competition with Goodyear in 1995. Firestone won one race that first year, but steadily improved until the tables were reversed in 1998 – when Goodyear won only one race and Firestone earned 18 wins.

Goodyear gave up on Formula 1 in 1998, and assured its CART teams that the reassigned F1 resources would return them to a competitive level of performance. Then, scarcely a month before the first race, Newman-Haas Racing switched to Firestone. Michael Andretti immediately picked up almost a half-second at the 1.5-mile oval at Homestead, Florida.

This leaves Goodyear with only four teams and five drivers. Penske Racing has fallen out of contention with Al Unser Jr's injury, leaving Walker Racing with driver Gil de Ferran the only Goodyear team with a hope of winning. Without top teams to work with, how can Goodyear hope to develop a better tyre?

The consensus among the few technical people in CART who are willing to discuss tyres is that the 1999 Goodyear tyres are 'grippy' when new, but 'go off' a couple of tenths of a second after a few laps, and then lose up to a half second over the next 20 to 30 laps. "The Goodyears even look slick," one engineer revealed. "They get shiny after a few laps, and the rubber is soft and sticky. They can be difficult on oval tracks, because the right-front seems to dig in all of a sudden, and the car can spin."

Another engineer described the difference this way: "The Goodyears get soft and sticky. The rubber rolls off and accumulates on the track. The Firestones stay a flat, grey colour and seem to abrade into a dust. They're more consistent than the Goodyears. They don't go off and the balance stays the same."

It seems that neither company really knows exactly why the tyres are different in this way. Certainly Goodyear would have solved the problem if its engineers knew what it was! "It's always been that way," is what people from both companies say off the record. The Goodyears have always had more grip when new, but deteriorate during use. The Firestones are a little slower during the initial laps, but they don't deteriorate as much. Goodyear seems to gain grip by using softer compounds, but its rubber lacks the cohesion and stability of the Firestone material.

Tyre companies underwrite CART testing and pay some teams to use its tires. Garage talk says that the Newman-Haas defection cost that team almost \$2 million per year. It left Walker Racing and driver Gil de Ferran to shoulder Goodyear's testing burden.

One imagines that Goodyear could recover in CART – but it could also switch to the IRL.

Paul Haney



# Tyre War





THE FUNDAMENTAL difference between Formula 1 and CART teams is that F1 teams design, build and develop their own racecars. Given a finite number of hours in a day, the F1 teams have to focus on reliability. They must spend most of their development budgets on wind tunnel work and software. Often, the suspension springs and dampers are regarded as a packaging problem.

CART teams, on the other hand, buy an integrated chassis, engine, gearbox and electronics package, allowing time for development of the chassis and driver. Dampers (shocks) are more important to many CART engineers than to their counterparts in F1.

Indeed, successful management of the mysterious triumvirate of tyres, dampers and driver is the key to low lap-times by CART racecars. This is less so when racing on aerodynamically important superspeedway tracks such as Michigan Speedway and its twin in California, but you still see many damper 'tweaks' even at these tracks.



**Top: Adjusting the Ohlins dampers in the three-spring front suspension of the 1999 Swift. Above: The Ohlins are a tight fit on the Swift ChampCar.**

Currently most CART teams use the Ohlins TT-44 damper. Of the 17 teams which brought their new racing hardware to CART Spring Training at Homestead, Florida in February 1999, only three had dampers other than Ohlins mounted on their racecars: these were Team Penske, Team Rahal, and Tasman, which had just been purchased by Forsythe Racing.

Tom Janiczek, Team Rahal engineer, assembles a unique damper using some parts from Penske Racing Shocks. The

# Dampers





Tasman/Forsythe team has traditionally used Koni 2812 dampers.

The interesting story among the non-Ohlins heretics is Team Penske, having changed from purpose-designed units by Penske Racing Shocks to a different damper from a mysterious European consultant.

One of the reasons for the current dominance of Ohlins, besides the high quality of the TT-44, is the withdrawal of Penske Racing Shocks as a supplier to CART and Indy

**The rear end of the 1999 Swift ChampCar, showing the third-spring system and Ohlins damper assembly.**

Racing League teams at the end of the 1996 season. Roger Penske considered Jeff Ryan, the general manager of Penske Racing Shocks, to be something of an unfair advantage, and decided to limit Ryan's racing involvement to Formula 1 and Team Penske. One of the realities of racing is the 'hero to

zero' situations among the technical people...

Team Penske's defection frees Penske Racing Shocks to supply CART teams once more, which might decrease the use of the now dominant Ohlins. Race engineers revere the latest technical gadget, and Penske Racing Shocks has continued development of its product line.

The Ohlins and Penske dampers are similar devices in that they both have a remote reservoir housing a separator piston and a gas volume. The Ohlins, however, is a double-tube design, using the volume between the inner and outer tubes as the flow path for the low-speed control circuit. Both dampers have a main piston with washer stacks on both sides.

The Koni 2812 damper is a monotube design with a separator piston between the gas volume and working fluid. While the Penske and Ohlins dampers have four different adjustments with 20 to 40 settings each, the Koni has only two adjustments (rebound and bump) with eight settings each. Some Koni proponents say that fewer adjustments cause less confusion.

At the time of writing, several of the CART teams were planning to test the Koni 2812, mainly due to its light weight and packaging benefits.

**Paul Haney**



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THE BIG NEWS in 1998 was that Ilmor Engineering switched to Magneti-Marelli electronics for the engine control unit and ancillary systems of its Mercedes-Benz ChampCar engine. Despite considerable success in Formula 1 (supplying electronic components to both Ferrari and Renault), the Italian company had not been represented in this the most lucrative customer car market since the demise of the Alfa Romeo IndyCar project at the end of 1991.

Specially commissioned by Ilmor (the race engine design and manufacturing arm of Mercedes-Benz) for the IC108E engine, the original system was assembled in the remarkably short time of five months. During 1998, it was supplied exclusively, but it is now more generally available. Alongside the engine itself, it has been the subject of continuous development work, and new features have been introduced for 1999.

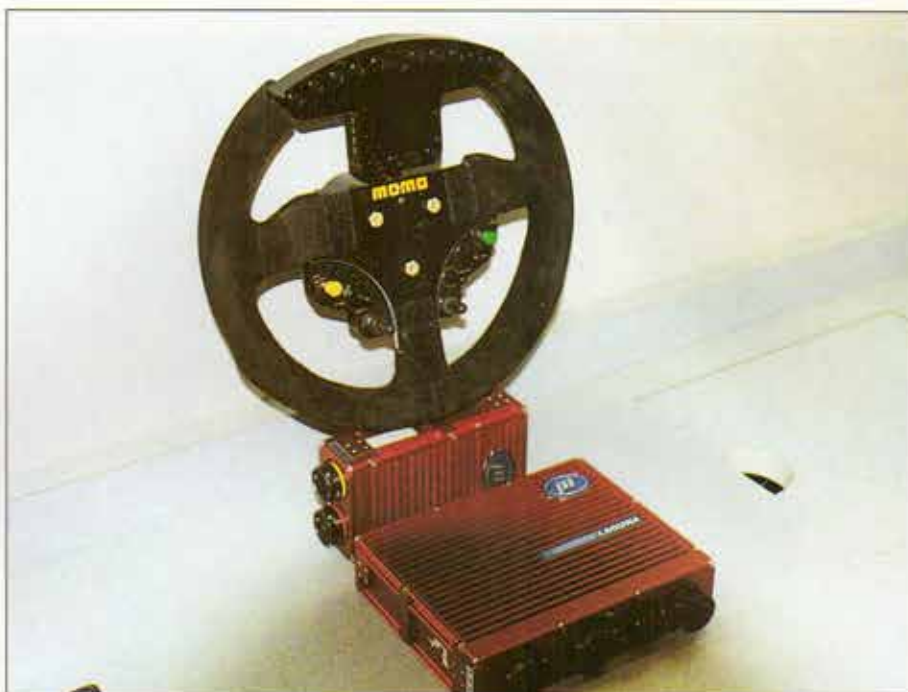
To the casual observer, the most noticeable change in 1998 was the introduction of a steering wheel mounted driver display, which was the first of its type to be seen in the series. For 1999, the number of display options available to a driver has been increased from three to six screens, with a further eight screens for use by engineers and technicians while the racecar is being prepared.

This year, steering wheel mounted displays from Pi Research and Visteon are also being used. TAG Electronic Systems has had a similar unit available for some time, but it will probably not be seen in ChampCar circles this year. Generally, these displays are supplied as sealed units to be mounted on a modified wheel, or occasionally the circuitry and display comes unboxed and is built into the wheel.

Internally, the ECU is now driven by an exclusive Motorola processor, increasing the speed of data handling. A typical application produces approximately 240 channels of data.

The Magneti-Marelli system contains a version of its 'DAS4' data-logger, and could meet any team's complete data-acquisition needs for both engine and chassis. At the time of writing, however, all the Mercedes teams had so far chosen to stay with Pi Research equipment for chassis data-acquisition.

Since the late 1980s, Pi Research has been the virtually exclusive supplier to the ChampCar market for chassis data-acquisition equipment. Other manufacturers have found it almost impossible to break in, other than to



**Top: Pi Research is developing its 'Laguna' data-acquisition system on 'Sigma' hardware, specifically for ChampCar racing. Above: Magneti Marelli is back in the CART marketplace for the first time since 1991.**

supply sensors or other specialist components. TAG supplied the Menard Buicks that contested the Indianapolis 500 before the introduction of the Indy Racing League and, for a while, Stack and Competition Data Systems supplied one or two teams.

For the Mercedes teams in 1999, this means that the two suppliers have agreed on a protocol so that data can be shared by CAN (Controller Automotive Network). Typically, engine builders like to keep control parameters confidential, although it is usual for engine data such as RPM, temperatures and pressures to be supplied, commonly as a one-way serial data stream, from the ECU to a team's chassis data-acquisition system. Where these systems come from different suppliers, it is often the latter that controls the driver display.

Since the Mercedes driver display is controlled by the ECU, there is a need for two-way communications. The two systems also use a single telemetry radio, although there are two multiplexed data streams which are separated on reception.

A significant new product for 1999 -

# Electronics





although it has had a low-key launch – is the new 'Sigma' hardware platform from Pi Research. This is a brand-new approach from the Cambridge, UK company, utilising the latest solid-state technology, and is designed to provide flexible and integrated hardware to meet the varying needs of its customers.

The launch of such a new system is fraught with difficulty. No matter how much laboratory testing is done (see *Pi Virtual Car*, V9N3), the real test comes when it is run in a racecar. For this reason, Pi Research took the decision to supply Sigma to a small number of customers in F1 and CART where it can be closely supported by trained engineers.

Sigma is a generic name for a family of components that can be assembled in a variety of configurations to meet the specific needs of a class of racing – or, for those with deeper pockets, a specific customer.

The 'Laguna' variant, designed specifically for ChampCars using Sigma components, is being used by only four teams, principally those using Ford power. With a year's racing behind it in 1999, the product will be considered ready to be made generally available in 2000.

Other teams will continue to use Pi Research 'System 5STAR', which had pretty much become standard equipment in 1998. The new steering wheel mounted display can only be used with Sigma hardware, so most teams will use a combination of the 'Compact Dash' with smaller satellite displays. The latter can also be built into a steering wheel, but the amount of information that can be displayed is limited.

CART rules limit the type of sensors that can be fitted to cars at race meetings – for example, ride-height sensors are not permitted. However, Pi Research still reports strong sales of the devices for use in testing. Kits for measuring driveshaft torque are also widely used, as is the 'Tyre Monitoring System'. The latter allows tyre pressure to be monitored in real-time and is primarily seen as a safety measure, especially on oval tracks where the consequences of a deflating tyre can be very severe.

As in previous years, the engine suppliers continue to go their own way on electronics. Engine data-acquisition is accommodated within the ECU, although generally, as noted above, a single telemetry radio is used to transmit combined chassis and engine data.

In the ChampCar series, fuel consumption is limited by the regulations, so fuel consumption is vital information for the teams as they update their strategies during a race.

None of the engine suppliers reported radical changes to its electronics for 1999, although all admitted to continued development. No doubt they are all determined to improve power output while maintaining or improving fuel consumption. The more flexibility they can give their teams over calling fuel strategy, the better their chances on track.

For many years, Ford has used its own electronics group to supply systems for engine control and ancillaries, including telemetry radios, and this appears to still be the case, although largely under the Visteon brand name.

Similarly, Honda produces its own electronics in association with Motorola, and is now using an updated version of the system that helped Ganassi Racing to its third consecutive championship last year.

Toyota, whose engines showed steady improvement during last season, continue with an updated system from Denso. The new ECU is based around a PowerPC chip.

**Steve Bunkhall**





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