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F1 – McLaren's Road Car
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SUSPENSION

It had been decided that the F1 would be a refined road car. A harsh, noisy ride was out of the question but so too was the compromised wheel control that results from road car rubber-bushed suspension. Steve Randle, the car's dynamicist, was therefore charged with creating a stable suspension which did not incur the NVH (noise, vibration, harshness) penalty of a rose-jointed race set-up.

Suspension design does not begin, though, when the chassis engineer starts to sketch wishbones and spring/damper units. In racing circles the first requirement is to arrange the car's principal masses correctly, a discipline which Gordon Murray imposed on the F1's design from day one.

Instant steering response needs a low polar moment of inertia in yaw, which means a wheel at each corner and the main masses — engine, fuel, occupants — close to the centre of gravity. In most road cars this is compromised by packaging limits, but Murray was having nothing of that. The F1's weight distribution (42/58 per cent front/rear) changes by less than one per cent from a full to empty fuel load, and even luggage is carried close to the centre of gravity.

Having achieved the right distribution in plan view the same must be done in side elevation. Starting with undesirable weight transfer under cornering and then correcting it with anti-roll bars is a compromise Murray could not accept, so the distances between the suspension roll centre and body mass centroid had to be the same front and rear. Since the roll centres must be low to avoid jacking effects, this meant the engine had to be as low as possible in the body. Dry sump engine lubrication also reduced engine height by valuable inches.

Only when these basics were correct could design of the suspension itself begin. Adaptive damping and ride height control were ruled out on weight grounds. Progressive rate springing was omitted too but for different reasons. First, the only way to achieve a stepless increase in spring rate is either by using complex pushrod linkages or costly taper-ground springs. Second, too much progression can suddenly increase weight transfer when a wheel hits a mid-corner bump, making handling unpredictable. What small amount of wheel rate progression there is in the F1 is an inherent feature of the suspension linkages themselves, supplemented by carefully optimised bump rubbers.

Wheel travel front and rear was set at a generous 90mm (3.5in) in bump and 80mm (3.1in) in rebound and the target unladen bounce frequencies at 86 cycles per minute (1.43Hz) at the front, 108cpm (1.80Hz) at the rear. With the finalised car slightly over target weight, the actual ride frequencies have fallen slightly to 84.5 and 105cpm. Although these frequencies are higher than those of everyday road cars, they are still low for a sports car of this performance potential.

It was the wheel rates and wheel travel which determined the downforce generated by the underbody. Too much downforce would simply have squashed the car on to its bump stops, making the handling dangerously unpredictable at high speeds.

Describing the suspension as double wishbone sells it ludicrously short. Its cleverness lies in how longitudinal wheel compliance has been engineered in without loss of wheel control. It is this compliance which allows the wheel to move backwards when it hits a bump, endowing the F1 with its remarkable ride.

Murray didn’t know how much longitudinal wheel compliance to provide. In racing cars every effort is made to eliminate compliance to maximise wheel control. So McLaren bought a Honda NSX and put it on the electro-hydraulic kinematics and compliance rig at Anthony Best Dynamics. A Porsche 928S and Jaguar XJ6 were also measured.

Different methods of achieving the required compliance are used front and rear in the F1 because the suspension pickup points, the forces acting on the wheels and the required geometrical constraints are different at either end of the car.

At the front wheels the priority was to prevent castor wind-off under braking, which compromises stability. Here, where braking and cornering forces are reacted through the tyre contact patch, a solution was adopted which McLaren calls Ground Plane Shear Centre. Subframes on either side carry the wishbones on rigid plane bearings but are mounted to the body by four compliant bushes, each 25 times stiffer radially than axially. These are aligned at tangents to circles which have the middle of the tyre contact patch as their centre.

The castor control of this arrangement is outstanding. Castor wind-off has been measured at 1.02 degrees per g of braking deceleration, whereas the NSX, 928 S and XJ6 measured 2.91, 3.60 and 4.30 deg/g. Toe change under braking and camber change under lateral force are also very small.

At the rear, where cornering and braking forces are again reacted through the contact patch but tractive forces through the wheel hub, a different configuration is used called Inclined Shear Axis. Complicated by the lower wishbone mounting on the gearbox, which is itself compliantly attached to the body, the suspension and engine mounts were designed as an integrated system.

Wheel control is again exceptional, the priority this time being to control toe changes under braking and traction. Measured values are 0.04 deg/g toe-in under braking, 0.08 deg/g toe-out under traction, both of which are negligible. Equivalent figures for the 928 S were 0.30 and 0.35 deg/g, both toe-in.

Otherwise the steering and suspension broadly conforms with road car practice. The castor angle and king pin inclination, for example, are both relatively low at 46 and 8 degrees respectively. However, the ground level offset (the distance between the centre-line of the tyre and where the steering axis meets the ground) is 25mm compared with the sub-10mm values typical today.

Aside from longitudinal wheel compliance, one of the critical determinants of a car’s ride quality and its ability to maintain consistent tyre contact on bumpy roads is the ratio of its sprung to unsprung masses. In a light car it is therefore essential to have light suspension — easier said than done in a vehicle which needs tyres and a braking system commensurate with a top speed of over 230mph.

Everywhere that unsprung weight could be saved, it was. The tyres — 235/45ZR17 front and 315/45ZR17 rear, developed specially for the car by Goodyear and Michelin — were kept as small as possible consistent with the tractive. braking and cornering grip demanded of them, and then subject to strict weight targets. Likewise the 17×9in and l7×11.5in cast magnesium wheels, which are finished in a tough protective paint.

Items such as the steering knuckles are specially manufactured because readily available alternatives were simply not light enough. The top wishbone/bell crank, which converts vertical motion of the front wheels into horizontal motion at the transversely disposed spring/damper units, is cast in aluminium alloy, while the lower front wishbone and both rear wishbones are (like the front subframe) machined from solid aluminium alloy on CNC machines. Although it may sound like an indulgence, manufacturing the wishbones this way was cheaper than forging them.

Despite this concerted effort to keep down the unsprung mass the final figures are, inevitably, still relatively high for an 1100kg car: 92lb (42kg) per corner at the front and 121lb (55kg) per corner at the rear, equivalent to sprung to unsprung mass ratios of 5.5:1 and 5.8:1. The equivalent ratios for a representative hatchback (Peugeot 306 1.8 XT) are 9.8:1 and 7.3:1.

Brake system development for the F1 was entrusted to the Italian company Brembo, well known for its motor racing expertise. But of course the design brief from Gordon Murray was explicit. In order to maximise brake pedal feel, he insisted that the brakes be unservoed. This ruled out anti-lock, which in any case would have added unwelcome weight and complication.

To achieve acceptable pedal effort demanded long moment arms at the wheels, so the ventilated discs are of large diameter — 332mm at the front and 305mm at the rear. Cross-drilling of the rotors provides improved pedal feel and helps clean the pad faces.

Even with the large discs and carefully contrived brake cooling, though, developing a friction material capable of hauling the car down from 200mph-plus speeds without fade, while still providing sufficient bite when cold, proved a considerable design challenge.

Front and rear brake calipers are all four-pot, opposed piston types as favoured in racing circles, not the floating calipers more typically used on modern road cars. Naturally, they are constructed of aluminium alloy to save weight. Because of their racing origins the rear calipers have no handbrake facility, so a mechanically actuated, fist-type caliper is added.

Gordon Murray’s insistence on maximum brake feel dictated the use of calipers machined from solid rather than bolted together from two halves. Again this is standard practice in the senior race formulae, and for precisely the same reason: it maximises caliper stiffness and so minimises lost motion. Pedal travel is only a little over an inch.

Although the F1’s pop-up rear spoiler was not intended to be an air brake — it is there to prevent forward migration of the aerodynamic centre of pressure when the car pitches under braking, increasing braking stability and allowing greater braking force to be applied at the back wheels — it actually raises the car’s drag coefficient from 0.32 to 0.39. Activation of the spoiler is controlled by brake line pressure, with a threshold speed of 40mph.

When the spoiler is raised, air pressure is developed at its base which is exploited to force cooling air to the rear brakes. Ducts at either end of the spoiler, which are uncovered when it deploys, convey the airflow down to the rear discs.

ENGINE

Although it is the numbing 627bhp peak power of the F1’s engine (codenamed S70/2 within BMW) which garners headlines, in many ways that represents the least of the challenges which faced the design team. The fact that the 550bhp originally demanded by Murray has been exceeded by a comfortable 14 per cent proves the point.

It was in other respects that BMW’s considerable experience in designing road and race engines was to prove invaluable. Firstly, Murray set the length and weight — 600mm block length and 250kg (to include all ancillaries, the exhaust and silencer). It finished up the correct length and only slightly too heavy (by 16kg). Secondly, this prodigious powerplant had to be rendered thoroughly user-friendly so it could trickle along in traffic as willingly as it would thunder along autobahns.

It is natural to regard any powerplant capable of delivering 627bhp and 500lb ft of torque (about 50 per cent more than a modern Formula One engine, incidentally) as a thoroughbred race unit, but that’s not so. It is instructive to compare the S70/2 with one of BMW Motorsport’s less exotic creations, the six-cylinder engine fitted to the M3. In most key areas — specific output, specific torque, peak power revs, bore/stroke ratio and compression ratio — the two units are matched to within 5 per cent Only in its length and weight does the F1 unit set itself significantly apart.

This is what you would expect of an engine which, in addition to being road-tractable, must be moderately stressed for a long service life and practicable maintenance schedules. In the course of its development the F1 engine was put through the same punishing 500-hoor bench test as all BMW road-going powerplants, and its nominal service interval is 5000 miles.

Emissions performance has not been compromised either. As in the M3 engine, secondary air injection is used to reduce pollutant levels during the critical warm-up phase. Until the four catalytic converters reach light-off — relatively quickly since they are closer-coupled in the F1 than in the M3 — air is injected into the exhaust manifold to burn off excess hydrocarbons produced by cold start over-fuelling.

It is a reflection of its short development time that the F1 engine uses, in the main, only tried and trusted technology from BMW’s mainstream units. The variable valve timing, for example, is closely based on the VANOS system used in the M3. This simple, hydraulically-actuated phasing mechanism retards the inlet cam relative to the exhaust cam at low revs, reducing valve overlap and ensuring good idle behaviour and low-speed torque. Higher up the rev range, under the control of the engine management computer, the valve overlap is increased by 42 degrees (25 degrees in the M3) to improve engine breathing and maximise power output.

Despite their common valvetrain technology, though, the F1 and M3 engines are tuned for significantly different torque characteristics. Whereas the M3’s torque curve has its maximum at 3600rpm and is virtually a plateau from 3500rpm to almost 6000rpm, the F1’s displays instead the inexorable climb of a traditional sporting engine, peaking at 5600rpm, only 1600rpmBelow peak power output. The F1 unit delivers a beefy 398lb ft at 1500rpm even so— 69 per cent greater than the M3’s peak output and quite sufficient to ensure vivid performance in a car weighing around 1200kg including driver.

In fact, ensuring that the F1 was not over-willing on small throttle openings posed one of the principal development difficulties. Making the engine fuss-free in traffic was not enough; it also had to be sufficiently controllable not to bury the car under the lorry in front at the merest twitch of the loud pedal. Careful design of the throttle linkage and TAG’s expertise in engine management were relied upon to achieve this.

Although considerable attention was paid to the induction system (length, diameter and surface finish of the inlet tracts, and the volume of the plenum chamber) variable geometry was resisted by BMW as an unnecessary complication.

A familiar problem in high-speed racing engines is mixture preparation. At the high inlet air speeds encountered at high revs there is insufficient time for the fuel to atomise fully if the injector is placed close to the inlet valve, as it is normally is in road engines with multi-point injection.

Although the F1 engine runs at nothing like the 13,000rpm-plus of state-of-the-art racing engines like the Ford HB, BMW’s engineers found that mixture preparation from a single injector was not ideal across the whole rev band, so two Lucas injectors are used per cylinder. The first, positioned close to the inlet valve, operates at low engine speeds while the second, positioned further up the inlet tract, takes over at high revs. A soft transition between the two, controlled by the engine management computer, covers up the switch-over.

Mixture preparation is further improved in the lower injector by air assistance. A narrow jet of air, drawn into the inlet tract by the partial vacuum created on the induction stroke, ‘shears’ the fuel spray and breaks it up into smaller droplets.

As you would anticipate in an engine of this sophistication, the closed-loop fuel injection is sequential. Fully mapped, contactless ignition is likewise no less than you would expect, each cylinder having its own miniature ignition coil, just as in the M5. Engine load is sensed by hot wire. Combustion conditions are sufficiently remote from knock limits that no knock sensor is necessary.

The materials usage in this engine, like the core technology, is also relatively conservative, drawing again on BMW’s production engines. No titanium valves or conrods here. Both the head and block are cast in aluminium, with a Nicasil coating to the cylinder bores providing the necessary wear resistance. The lightweight pistons are of forged aluminium, the con rods and the crank of forged and twisted steel, and the exhaust valves are sodium cooled. Significantly, most of these features can be found in the M5 powerplant.

One notable exception is the exhaust system, a bulky and potentially heavy item constructed, from the block to the silencer, of Inconel, a particularly durable, heat resistant grade of stainless steel which allows the use of a thinner pipe gauge (0.8mm). Further weight saving is achieved by making the large 65-litre silencer of titanium and having it double up as a crush member for rear impacts.

A race engine feature which Murray did insist on for the F1 was minimal flywheel effect. What the clutch mounts to is an aluminium plate no larger or thicker than necessary to transmit the engine’s torque, and which has minimal rotational inertia. This should endow the V12 with exceptional throttle response and rapid rev shedding on lift-off, permitting the fastest possible gear changes. Of course, this is only feasible in an engine without secondary vibrational couples (hence the pure 60-degree vee angle) and which is carefully balanced, otherwise the level of engine vibration would he unacceptable. BMW has also fitted a torsional vibration damper.

A second race car feature, found on very few road cars, is dry sump lubrication. Although more complex and costly than a conventional wet sump, it shaves vital inches from the height of the oil pan and so allows the engine to be mounted lower.