The car in front of you

Ian Bamsey explores the evolution of the Toyota Formula One engine, revealing the technology underpinning modern Grand Prix racing

How did we travel from the high-boost era of the 1980s to today's high-revving naturally aspirated Formula One engines?

The journey was in two phases. The first spanned the 1990s, when engine manufacturers first started aggressively exploring the region above 12,000 rpm, steadily moving towards 18,000 rpm (which today by regulation is the engine speed limit). The second phase, over the past ten years, only briefly witnessed further speed

The Toyota Formula One engine has always had a 90° bank angle and its clutch on the end of the crankshaft (this is the original V10) increases, to 20,000 rpm, and was characterised by an increasing mileage requirement. Instead of having to run only one Grand Prix race, these hugely stressed engines now have to run three complete meetings.

In tracing the development of the Toyota Formula One engine, we explore here in depth that second phase. In its final 2.4 litre V8 frozen-specification guise, the engine developed by TMG continues to be used to power the test car that Toyota fields for new tyre supplier Pirelli; TMG is Toyota's motorsport facility based in Cologne, Germany, which ran the Japanese company's Formula One programme. The design of the V8 TMG produced for Toyota was the subject of a Dossier in *RET* issue 49 (1) and here, thanks to further generous cooperation from TMG, which both designed and developed it, we are able to chart its evolution from Toyota's initial decision to enter Formula One.

With all Formula One engines by regulation now frozen in specification, this is the revealing and exclusive story of how a state-of-the-art contemporary Grand Prix power unit came about.

Components of the original V10 engine

Introduction

The Formula One turbo era of the 1980s lasted until 1988, after which all engines had to be naturally aspirated. Initially the displacement limit was 3.5 litres, and in the early '90s the FIA also decreed 3.5 litre naturally aspirated engines for Group C. At the time, Toyota was active in Prototype racing and it designed a naturally aspirated 3.5 litre V10 for its 1992 Group C car.

Group C racing fizzled out in 1994 and Toyota did not follow arch-rival Peugeot in developing a spin-off Formula One engine. Then, for 1995, the Formula One displacement limit was cut to 3.0 litres. By this stage the FIA had clamped down on fuel development, enforcing gasoline that was little better than regular roadside unleaded in terms of performance enhancement. The 1995 3.0 litre Formula One engines were a mixture of V8, V10 and V12 configurations.

As engine speed steadily rose, undoubtedly the strongest 3.0 litre engine was the Renault V10, which in 1995 produced about 700 bhp at 15,600 rpm. By 1997 the best engines had gone on to eclipse 750 bhp, for example the Ilmor V10 making 760 bhp at 16,200 according to designer Mario Illien. The rival Renault and Ferrari V10s made a comparable output.

By 1998 all Formula One engines were V10s, and that year new chassis and tyre regulations left the cars inadequately shod at the rear. That put the emphasis on preservation of the rear tyres and, from the engine perspective, weight was more significant than ever as designers strove to push the car's centre of gravity forwards. A front-end timing drive was called for and there was a trend to linerless aluminium alloy cylinder blocks, to save weight.

The years 1998 to 2000 were also notable for the exploitation of aluminium-beryllium pistons by Ilmor Mercedes, these both saving weight and increasing thermal resistance over the regular 2618 aluminium alloy. New materials regulations for 2001 effectively outlawed that beneficial approach, decreeing 40 GPa/(g/cc) as the maximum specific strength for all components (for 2000 that figure had been decreed as the maximum for all except internal engine components).

In the meantime, having reached 800 bhp in 1999, by 2000 the Ilmor engine was running to a maximum speed of 18,000 rpm, and was then making peak power of 820 bhp at 17,500 rpm. That was the state of the art in a season for which the FIA decreed there to be a maximum of ten cylinders. That move scuppered the plans of Toyota and Cosworth, both of which had V12 projects underway.

2000-2001

When, in January 2000, Toyota switched instead to a V10 3.0 litre engine, the design team was led by Luca Marmorini, previously a Ferrari Formula One engine engineer (he remained with TMG until 2009). Soon after embarking on the design of a V10 he remarked to the author that since the Toyota race programme was not scheduled to start until 2002, the new engine could not afford to be a conservative design, otherwise progress by its rivals would surely leave it wanting.

Toyota's initial Formula One engine was officially designed RVX-01 (Racing Vee Ten – 01). It was known in-house as the 'B' engine, following on from the V12 design. It had a 90° rather than the conventional 72° measure as its bank angle (this being an approach pioneered by the 2000 Ferrari V10). Linerless, it had a 95.1 mm bore, a front-end timing drive and, at the outset, its weight was 109.55 kg.

The B engine had its first dyno run in September 2000, its first track test in May 2001. In the summer of 2001 the strongest Formula One engine was almost certainly the BMW V10, which was developed to produce 880 bhp according to recently published information from the company (2). By August 2001, Toyota had engine speed 500 rpm up on initial testing and then, at close to 18,000 rpm; its as-yet unraced V10 made almost 800 bhp. ▶

THE ENGINE STRUCTURE

The first lightweight V10 engine was the Yamaha of 1996-97 produced by EDL, which featured screw-in liners. Alternatively, a linerless block could help, and Cosworth pioneered that approach in 1998 with its V10. By the time Toyota started racing, that was the conventional approach. No other use of screw-in liners is known in recent Formula One times.

An alternative is the integral head and block, as used by Hart for a Formula One I4 of the high-boost turbo era. Dispensing with the head gasket eliminated not only potential gasket problems but also a barrier to the conduction of heat, and the weight and complexity of heat attachment bolts. The combined linerless structure was stiffer and lighter, and provided more scope for coolant passages.

On the face of it, the main drawback of an integral structure is the difficulty of manufacturing it, but improvements in manufacturing technology have made the concept increasingly attractive. In 1991, Mercedes used the concept for its naturally aspirated 3.5 litre 180° V12, which was only used in Group C, never Formula One.

However, more recently, BMW produced a prototype 3.0 litre V10 Formula One engine using the concept. The deployment was successful enough that its initial study for a 2006 2.4 litre V8 embraced it. But the eventual FIA ruling on minimum weight steered BMW to the more conventional solution of a detachable head and linerless block.

2002

The lessons of the B engine led to a redesigned C, which followed the same basic pattern and came in essentially at the same weight (109.11 kg). With this engine Toyota made its Formula One debut at the start of the 2002 season. Toyota has never published power output figures for its Formula One engines. Each year at the mid-season British Grand Prix event, *RET* estimates the power of all current Formula One engines, not by any quasi-scientific form of measurement but by the straightforward approach of asking key engine and chassis engineers – who know their own output and go to great lengths to judge the performance of their rival units against it – to establish a consensus table. Toyota was estimated by this method to have reached 830 bhp mid-season with its first Formula One race engine.

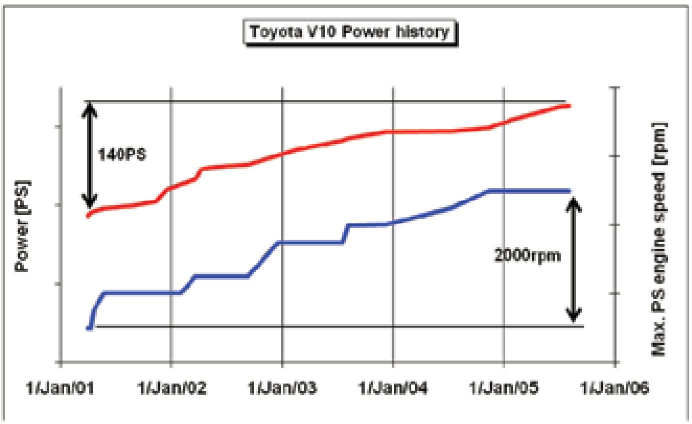
In 2002, BMW produced the first V10 to reach 19,000 rpm, and by the end of that season its output was 895 bhp (2).

2003

In an effort to take Toyota to the sharp end of the grid, for 2003 there was a complete redesign of the previous B/C engine. Reflecting increasing engine speed, the new D engine increased the bore from 95.1 mm to 96.8 mm, yet was nevertheless more compact. The D also had a lower crankshaft height than its predecessors, helping to lower the centre-of-gravity height. At 101 kg, it was significantly lighter than the C engine. It also offered a step up in performance.

The FIA brought in overnight *parc ferme* regulations for 2003 Formula One events, so a car had to race with the engine used in qualifying. While this added only a marginal amount to the required mileage, it did add the toughest period of running for any engine. Nevertheless, by mid-2003, both BMW and Honda had exceeded

Evolution of the power output of the Toyota V10 engines



900 bhp. At the British Grand Prix, *RET* estimated 910 bhp for those engines and 890 bhp for the D-spec, which was the first Toyota V10 to run to 19,000 rpm. It was developed to produce more than 900 bhp by the end of the 2003 campaign. BMW claims it reached 940 bhp by the end of 2003 (2).

2004

For 2004 there was a significant increase in required mileage, the engine now mandated by the FIA to run the entire race weekend. Mileage thus went from about 370-400 km (qualifying and race) to 550-700 km (the exact figure according to team usage policy, and typically about 600-650 km). In view of this, the E engine was essentially an evolution of the D engine with painstaking detail work providing the required increase in mileage. Despite that, the best part of a kilo was shaved from the weight; the E weighed about 100 kg.

Revealing the innards of the 2002 engine