Summary of Honda Formula One Engine in Third-Era Activities

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ABSTRACT

Honda has entered six models of V-type engines with 10 cylinders (below, V10 engine) and three models of V-type engines with eight cylinders (below, V8 engine) as third-era Honda Formula One engines. The goals of development were to achieve output approaching that of the second era, the turbocharged engine era, with natural aspiration, and to realize a smaller, lighter engine with a low center of gravity, focusing on the vehicle's height of gravitational center, weight distribution and aerodynamics. Revising the structures of different parts, modifying materials and surfacing processes, and making design engineering and evaluation technique progress among other advancements resulted in per-liter power that is 100 kW/L greater than a second-era naturally aspirated V10 engine, as well as having approximately 6500 rpm higher engine speed for peak output, being more than 50 mm shorter in length and about 70 kg lighter, having about 50 mm lower crank center height and more than three times the mileage. Honda has proceeded with development of V8 engines with the goal of high engine speed and won a third-era victory. However, because of regulations restricting maximum engine speed and an engine development freeze due to homologation regulations, issues relating to drivability (below, DR) have been left unsolved.

1. Introduction

Development of the third-era Honda Formula One engine began in the autumn of 1998 with the program of returning to racing in 2000. Honda has launched a total of nine engines: six V10 engines starting with the RA000E in 2000 and continuing through the RA005E; and three V8 engines from the RA806E to the RA808E. This article gives an overview of Honda's third-era activities, looking back on second-era engines and recounting the movements through the third era, then reviewing the progress made by comparing second-era and third-era V10 engines.

2. Trend from Second Era to Third Era

2.1. Regulations

Development of second-era engines continued for 10 years, 1983-1992, with Honda as an engine supplier. During that period as well, engine regulations were changing greatly, and in 1983, when Honda restarted Formula One racing, the 1.5 L turbocharged engine was the most common type. Subsequently, regulations limiting boost pressure and total amount of fuel consumption were put into place to limit outputs of more than 740 kW (1000 hp), and as Table 1 shows, the transition to 3.5 L naturally aspirated engines began in 1987, while from 1989 all engines became naturally aspirated with a maximum of 12 cylinders. In 1995, after Honda had taken a break from being a works engine supplier, engine displacement was diminished to 3.0 L and the V10 engine became the mainstream. From that point on, changes in regulations became less significant, and the era of the 3.0 L V10 engine lasted 11 years until 2005. The third era began in 2000 and lasted for six years under these regulations. Subsequently, the engine regulation changed to a 2.4 L V8 in 2006, and in the inaugural year of the V8 engine, our victorious third-era engine was realized.

2.2. Output

The key requirements of second-era racing engines were output, drivability, reliability, lightness of weight, compactness, and fuel consumption, which are the same elements needed today. A different era and different regulations, however, mean different priorities, so second-era engines, built when vehicle aerodynamics were still simple and slick tires were allowed, were developed strongly focused on output.

As Fig. 1 shows, the Honda Formula One engine

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Table 1 F1 engine regulations

Year	Amendments to F1 Engine Regulations
1984	Engine capacity (with supercharging) : 1.5 L maximum (without supercharging) : 3.0 L maximum Number of cylinders : 12 maximum Fuel storage capacity : 220 L maximum Fuel RON : 102 maximum
1986	Engine capacity (with supercharging) : 1.5 L maximum Fuel storage capacity : 195 L maximum
1987	Engine capacity (with supercharging) : 1.5 L maximum (without supercharging) : 3.5 L maximum Manifold pressure (turbocharged engine) : 4.0 bar maximum Fuel storage capacity : 195 L maximum
1988	Manifold pressure (turbocharged engine) : 2.5 bar maximum Fuel storage capacity (turbocharged engine only) : 150 L maximum
1989	Supercharging prohibited Engine capacity : 3.5 L maximum
1991	Fuel RON : 102 maximum , Fuel MON : 92 maximum
1992	Fuel RON : 100 maximum , Fuel MON : 90 maximum
1993	Fuels of a kind used by general public mandatory
1995	Engine capacity : 3.0 L maximum Fuel sampling at circuit Fuel approval before use
1999	Throttle and pedal relationship fixed whilst car is in motion Restriction for engine and clutch control (traction control prevention) Cooling system pressure 3.75 bar maximum Fuel incorporate 2000 EU limit
2000	Number of cylinders : 10 maximum Fuel incorporate 2006 EU limit
2001	High specific modulus of elasticity material (Be-Al, etc.) completely prohibited Traction and launch control permitted
2002	Spraying substances other than fuel into engine prohibited
2003	Parc ferme rule (no engine change between qualifying and race)
2004	1 engine for 1 race event Launch control and fully automatic gear shift prohibited
2006	90 degree V8 2.4 L engine 1 engine for 2 race events
2007	Engine homologation (freezing of engine main component development) Rev limit : 19000 rpm
2009	8 engines throughout 1 race season Rev limit : 18000 rpm KERS (hybrid system) permitted

already had output of 440 kW (600 hp) during the 1983 races, and the era of the 1.5 L V-type engine with 6 cylinders equipped with turbochargers (below, V6 engine) further enhanced output by increasing boost pressure. By 1986, the engine had achieved 770 kW (1050 hp), actually increasing output by more than 300 kW in three years, with the result that regulations were changed to prohibit supercharged engines.

Another factor that increased output in this era was the development of fuels. As Table 1 shows, under the regulations of this era, there were few limitations on fuel, and in particular no restrictions on energy density, so fuels came into use that deviated substantially from commonly available products. Starting with the 1992 Hungarian Grand Prix, teams were obliged to use premium levels of market fuels and the use of special hydrocarbons was prohibited, so output actually dropped by 32 kW (43 hp) as compared to the German Grand Prix that preceded it. This example demonstrates how fuel contributed to engine output.

In the third era, even stricter regulations came into effect on premium levels of market fuels in 1999 and thereafter to prevent excessive competition, and there were no major increases in output as a result of fuel as in the second era. In the V10 engine era, however, when the free development of engines was allowed, the performance of naturally aspirated engines advanced to rival the output of the second era (the turbocharged engine era). This shows that the technology of the engine itself had advanced at high speeds, and some of the content relating to this will be mentioned below in the comparison of second-era and third-era engines.

2.3. Weight

This part discusses changes in the weight of engines. As Fig. 2 shows, the weight of the engine alone was 120-130 kg even during the V6 era, and there have even been some naturally aspirated V10 or V12 3.5 L engines weighing 155-160 kg. Magnesium and titanium were used at the time as materials to make engines lighter, but even so engines could hardly have been called very light.

In 1992 and beyond, although this was not a works activity for Honda, engine output seemed to stagnate, as Fig. 1 shows, in part because of the impact of regulation change and, the lack of competition among works engine suppliers. For that reason, the chassis constructor teams started emphasizing weight distribution and aerodynamics, and making the engine lightweight with a low center of gravity became more important than before. As a result, engine development advanced year by year during the era when Honda was racing as Mugen-Honda, and engine weight reached as low as 122 kg by 1998.

Coming into the third era, there was even greater need for lightness of weight, and development has continued until V10 engines finally weighed just 89 kg.

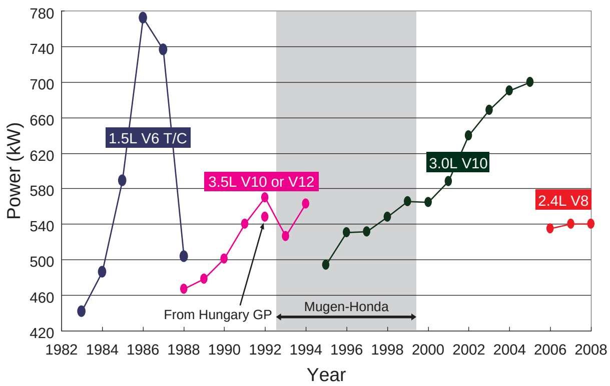

Fig. 1 Honda F1 engine power

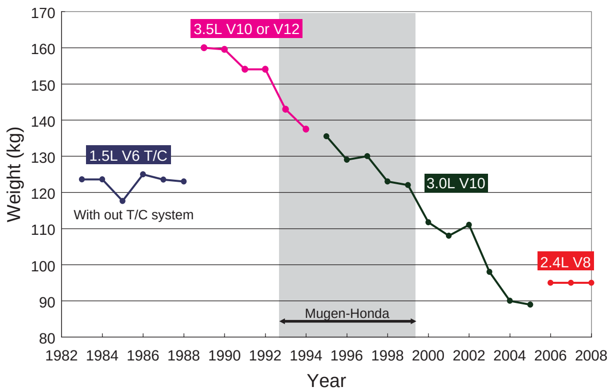

Fig. 2 Honda F1 engine weight

Table 2 RA100E versus RA005E

	RA100E	RA005E
V-Bank angle (degree)	72	90
Power (kW/L)	143	240
Ps peak Ne (rpm)	12250	18700
Engine length (mm)	633.0	581.5
Engine weight (kg)	160	89
Crank center height (mm)	109.0	58.5
Mileage (km)	400	1400

3. Comparison of RA100E and RA005E

3.1. Comparison of External View

The following compares the RA100E in 1990 and RA005E in 2005, two engines of the same V10 configuration from the second and third era, respectively, to discuss in broad terms the progress that was made over 15 years. Table 2 shows comparative values.

As the photos of the external view shown in Fig. 3 indicate, the RA005E is not so high. This difference has to do with the change in V-bank angle from 72° to 90°; naturally, an engine with a large V-bank angle will have a low center of gravity. In a V10 engine, when the left and right banks have a common crank shaft pin, a V-bank angle of 72° with even firing intervals would theoretically be advantageous, considering the load placed on the pin. However, in the third era, engines were already using an 80° angle as early as 2000, the inaugural year of that era, daring to choose uneven firing intervals. In 2001, there was an angle of 80°, in 2002, 94°, and since 2003, 90°, so priority was not given completely to even firing intervals. The reason is that enhancement of aerodynamics and a lower center of gravity took priority as elements determining vehicle speed in Formula One cars in the third era; the basic structure prioritized the total car packaging layout instead of chasing some ideal for the engine itself, which is after all just one component of the vehicle. Renault went so far as to use V-bank angles of greater than 100° for a time in its try for a lower center of gravity. The V8 engines of the time had to have an angle of 90° by regulation; there was no choice in the matter. With V10 engines, all teams were already using 90°, so there was no problem with this. However, it means that no unique engines such as Renault's would come into existence thereafter.

RA100E RA005E

Fig. 3 Engine photo

3.2. Comparison of Output

A comparison of output per liter shows that the RA005E's power is 240 kW/L, or about 100 kW/L greater than the RA100E's 143 kW/L. The elements of enhancing performance are to increase volumetric efficiency and combustion efficiency and to reduce friction; these are fundamental to engine development and there is nothing special about them. Since this concerns naturally aspirated engines, engine speed is the dominant factor in volumetric efficiency, and the RA005E's peak output was achieved at 18700 rpm, 6500 rpm higher than the RA100E's 12250 rpm. Necessary conditions for achieving high engine speed are to stabilize valve behavior by reducing valve train equivalent mass and to increase durability and reliability of the reciprocating system. The Honda Formula One engine reduced equivalent mass specifically by changing from a direct-driven tappet system to a rocker arm system, and furthermore switching materials from titanium to a titanium/aluminum alloy for the valves and making the stems more slender. In the reciprocating system, Honda was able to reduce the weight of moving components by using aluminum matrix composite (AMC) pistons and box-structure connecting rods (below, conrods) made with an intermetallic bonding production method. By additionally using an alloy with good heat conduction for the conrod bearing (plain metal), the engine reduced the temperature of sliding against the crankshaft pin and achieved reliability at high engine speed.

3.3. Comparison of Overall Length

A comparison of engine dimensions shows that, whereas the RA100E is 633 mm long, the RA005E is 581.5 mm, or 51.5 mm shorter. Cylinder bores are 93 mm and 97 mm, respectively; the RA005E's bore diameter being 4 mm larger means that its length would be 20 mm longer, or 653 mm. Converted from that basis, it is 71.5 mm shorter.

Broadly speaking, there are three technical elements that made the shorter engine possible. The first was that it became possible to join the cylinder block (below, block) and cylinder liner (below, liner) into a single piece. In the earlier Formula One engine, the block and liner were separate, and they were generally built into wet liner structure so that cooling water could make direct contact. The separate structure has commonly been used because the liner undergoes special surface finishing where it slides against the piston, which makes it more convenient if it is separate from the block. The separate structure has had the additional advantages of offering a high degree of design freedom for the water jacket of the block itself, and during rebuilding, only the liner needs to be replaced. However, recent advancements in block casting technology and piston sliding surface-processing technology have made it possible to integrate these into a single piece. Moreover, higher engine speed has decreased block life, whereas engine assembly life has increased due to regulation requirements. Thus, engine assembly life and block life are now about the same, so there is less meaning in replacing only the liner; in the third era, the movement to a single piece has advanced, and this is more or less the case with other engine suppliers. In addition, the structure of the gasket that seals between block and cylinder head has changed greatly, so the gasket is now an O-ring type, sealing just the bore perimeter, instead of the old sheet form. As a result, the dimension between cylinder axes is shorter, making it possible to reduce engine overall length.

The second technical element is that advancements in technology to make gear materials stronger and reduce gear vibration have enabled a change of valve gear train with a reduction system to one with a serial system, thus making it thinner.

The third element is that advances in conrod bearings have allowed them to become narrower, which has reduced the amount of offset of the left and right banks.

3.4. Comparison of Weight

The weight of the RA100E is 160 kg while that of the RA005E is 89 kg. This reduction of about 70 kg in 15 years represents a weight reduction of more than 40%. Even just looking at the third era, the RA000E in 2000 was 112 kg, so engines reduced 23 kg in five years: an average yearly reduction of 4 - 5 kg. Although the push to lower weight stagnated for a time in 2002, the engine resumed reducing weight in 2003. Magnesium and titanium, useful for reducing weight, were already being used in the second era, so in the third era it has been thought that there are few advantages of using these materials. Advances in design technology can be mentioned as a reason for even further weight reduction. From the second era to sometime in the third era, design methods were mostly 2D, but starting around 2003, 3D gradually came into use, and with the implementation of CATIA V5 shown in Fig. 4, completely 3D design and CAE became easy to use at the designer level, and engines became correspondingly lighter. In order to prevent excessive competition, current regulations stipulate that V8 engines must weigh at least 95 kg, and they prohibit the use of magnesium, titanium, resin, and CFRP as materials. If these restrictions were not in place, calculations suggest that designs weighing about 78 kg would be possible, which indicates how much the technology to reduce engine weight has evolved.

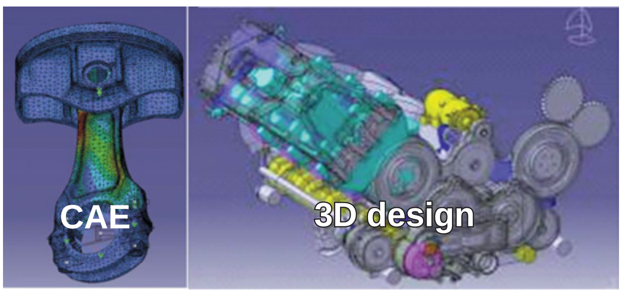

Fig. 4 CATIA V5

3.5. Comparison of Crank Center Height

Crank center height is a factor that determines the engine's center of gravity and affects the vehicle's overall height of gravitational center, and as such is an important dimension determining vehicle dynamics. Current regulations thus stipulate that it must be at least 58 mm high to prevent excessive competition, and furthermore that the engine's center of gravity itself must be at least 165 mm from the bottom of the engine. Whereas the RA100E has a crank center height of 109 mm, in the RA005E it is 58.5 mm, or more than 50 mm lower. Broadly speaking, there are three technical elements that made this possible. The first is stronger ferrous materials, which allow for more slender crankshafts, as well as more slender conrod bolts. As a result of combining these newly developed parts, smaller conrod locuses are realized. The second element is advances in crankshaft counterweight design engineering. Materials with high specific gravity, such as tungsten, that are used as balance weights can now be bolted down directly under even high levels of centrifugal force such as at 20000 rpm, which has reduced the crankshaft's radius of gyration. The third element is modifications in clutch friction material and construction, so that even with a smaller diameter it is still possible to get sufficient torque transmitting capacity.

3.6. Comparison of Mileage

In 1990, when the RA100E engine was in use, a single driver used at least three engines during one racing event, because they were allowed to use one for the Friday free practice, one for the Saturday qualifying practice, and one for the Sunday final race. Since the mileage of the final race is about 300 km, the engine only needed to have reliability of 400 km, including the Sunday morning warm-up session. The RA005E engine, on the other hand, had to have durability of about 1400 km, because it arrived in the second year of regulations, begun in 2004, which intended to reduce high engine costs by requiring that a smaller number of engines be used. After that, each driver had to use just one engine during two race events. This restriction remained in force until 2008; beginning in 2009, each driver was permitted to use a maximum of eight engines in a year. As noted above, advances in the engine itself and in evaluation methods can be mentioned as technical elements that more than tripled the durability and reliability of engines as compared to the second era. In addition to the previously mentioned advances in the engine itself, there have also been advances in surface modification technology, as exemplified by diamond-like carbon (below, DLC) coating. The evolution of DLC has been particularly remarkable, so that, in almost all of the major sliding areas of a Formula One engine, DLC of one specification or another is currently used. If this were to be prohibited, it is likely that both reliability and performance would diminish greatly. The next advancement is in evaluation methods, the biggest factor in which is the use of low-inertia transient dynamos (dynamos with the same inertia as wheels and tires), which allows personnel, using the engine alone, to perfectly simulate driving a circuit. Engine durability and reliability are affected when using traction control or by irregular revolution resulting from ignition cuts when engine speed is restricted, but in the past it was only possible to reproduce this by actual driving, so durability and reliability could not be definitively guaranteed in advance for all 16 or more circuits.

4. V8 Engines

Development of V8 engines, the use of which has been obligatory since 2006, began in November 2004. In May 2005, before any other team did so, Honda conducted test runs on the Jerez circuit in Spain with a prototype engine, a V8 adapted from the 2004 V10 model. Having a goal of maximum engine speed of 20000 rpm in Honda's 2006 racing engine, development was carried on at a quick pitch, with first firing test on dynamometer in August 2005. The result was Honda's only third-era victory, at the summer Hungarian Grand Prix, which proved the excellence of Honda's V8 engine. Development was proceeding that sought an even higher engine speed for 2007, but regulations limited engines to a maximum of 19000 rpm. Meanwhile, homologation regulations limited annual development of engines themselves, and engine specifications have been determined that have become the basis for the development freeze since 2008, specifications that Honda was unable to deal with satisfactorily. As a result, transient combustion has not stabilized, and the 2008 prohibition on traction control has additionally caused DR issues to emerge. Honda has taken measures as far as development is possible, but has not achieved any fundamental solutions. Since DR was still insufficient, the season was a disappointing one. Talks with the FIA resulted in a partial lifting of the development freeze for 2009, and Honda began development in October 2008 to solve DR issues in anticipation of the opening of the next season, and confirmed in December that performance was as targeted. Unfortunately, Honda has withdrawn from Formula One activities, so it has not been possible to prove the results of enhancements. The emphasis in current Formula One engine development is not to put the foremost priority on maximum output, which has always been considered Honda's strength, but rather on improving output characteristics, particularly in the range where they affect DR, and on somehow eliminating irregular combustion. The reason is because even if output were increased by 10 kW, it would only improve lap times by less than 0.1 seconds, whereas in comparison poor DR makes the driver lift off the throttle pedal while coming out of the corners, resulting in a loss of more than 0.5 seconds. Honda engineers need to do a lot of reflecting on the fact that there has been little development emphasizing this.

5. Conclusion

This paper has looked back on Honda's Formula One engines, using numerical values to compare the second and third eras, which reminds us anew of how amazing the technical advances have been over the course of 15 years. Because there are presently so many regulations, there is little room for further advances such as these, but it is still supposed that the technology will advance bit by bit hereafter. Regardless of whether Honda returns to Formula One racing, the company feels it must endeavor to preserve the information network it has created and pursue further technical advances (concepts). Otherwise, in such a rapidly advancing world, it may take a great deal of time to catch up if we again get the chance to take part in Formula One engine development.

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