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# Looking Back on Assembly Activities –Racing Spirit–

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## ABSTRACT

Numerous technologies were developed and put to use in races during Honda's third-era Formula One activities. This paper introduces assembly activities from development tests to the racetrack.

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## 1. Introduction

Honda's third-era Formula One assembly activities began with several goals: "no dropping out of a race because of human error;" "no supply delays;" "reflect development issues in blueprints;" and "pass down technological skills." Based on Honda's second-era experience, these four elements were essential for race management, and activities were always pursued with a consciousness of these targets as the path to victory.

This article introduces these activities by dividing them into those that are in the factory domain, taking place at Tochigi R&D Center (HGT), which oversaw development of new technical items and the assembly and supply of race and test vehicles, and at Honda Racing Development (HRD); and those in the circuit domain, which supported race and running test sites.

## 2. Factory domain

### 2.1. Startup of Honda Formula One Third Era

The third era started in 1999 by organizing the team strength so that primarily those members who had supported the golden era of Honda Formula One in the second era could pass down their technical skills to new members, increase development speed and pursue supply of equipment for races. Passing on everything to the new members involved a lot more than just writing a manual and making them read it; it was a lot of work!

This section first gives a simple explanation of how technological skills relating to the work of the assembly crew were handed down.

At the development stage, one repeatedly assembles and dismantles previously developed single-cylinder engines, demonstration bench engines, durability engines and running test engines, after which one checks the new

specifications, looks for issues and feeds back results of countermeasures to try to bring blueprints to fruition. One assembles an engine built to the latest specifications and then sends it to the racetrack. Engines used in races are dismantled, malfunctions are found and then this goes into the next cycle of activity. In this way, the assembly domain is always involved, from the beginning of development until race day.

Although one casually talks about engine assembly, a Formula One engine is not simply put together using as-is components that are in inventory. These are very delicate engines: with the emphasis on performance, they have only the minimal amount of durability and are subject to approximately five times the engine vibration as mass-produced engines, and the slightest error or even one component quality defect can easily cause them to break down.

To assemble such an engine, there must be no errors. Components must be checked assiduously one-by-one so that not even a fine burr is overlooked, and so that each component can perform to its maximum extent. The assembly crew is part of the final process, where one can touch actual articles and check them with one's own eyes, and quality must be protected here so that the team can win the race. Similarly, during dismantling, one visually senses malfunctions and feeds back information to bring blueprints to fruition.

Assembly is furthermore required to supply equipment for development and races with enough speed to keep up. In fact, the authors cannot remember a single season in Honda's Formula One activities in which there was not a need for emergency component replacement because of malfunction, or no repairs on engines experiencing trouble. It is always a battle against time, so one has to work with efficiency, speed and reliability.

To achieve this, the biggest issue is giving new

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members the ability to spot malfunctions as well as speed and work precision.

It is hard for new members to learn these things in a short period of time, and there was a noticeably large experience gap between them and Honda's second-era Formula One members. The new members started with their experience at HGT, got more experience from being sent to HRD, and finally grew into track mechanics.

These members prepared on average 1000 engines per year, including new assembly, rebuilds and reassembly (Fig. 1), with the number of reported troubles averaging 182 per year, thus contributing greatly to bringing blueprints to fruition.

## 2.2. Development of Quality Enhancement Measures

During nine years of activities, the regulations have changed several times to cut costs: the usage restrictions on engines have changed so that the guaranteed usage distance is 1 500 km, up from 300 km; and whereas there were non-restrictive rules allowing practice, qualifying and race engines to be changed, this was changed to require one engine per race-event, and then one engine per two race-events. The regulations have also changed in ways that affect race strategy, with a penalty now being assessed for changing engines. This has increased the requirements for engine quality and durability.

Originally, our members thought that the old ways of doing things were sufficient, but extending guaranteed engine usage distances was a new frontier for our Formula One activities up to that point, and also represented a great opportunity to further enhance quality and durability.

First, members strengthened quality checks of each component. They anticipated the possibility of impurities getting into places invisible from the outside, such as oil passages, and then before assembly used an endoscope to do a full check. For phenomena such as injuries on the sleeve, it was decided to do a bench check prior to shipping, then check piston and sleeve status and look for impurities with an endoscope immediately before shipping, and then supply equipment to the racetrack. Besides this, the number of check items was increased

for all assembly processes and countermeasures were added to prevent troubles before they could occur, which strengthened the members' efforts to eliminate defects that were their fault and prevent faulty components from shipping. This further enhanced members' awareness of quality and made them more mindful of the engines they themselves assembled.

During assembly, more malfunctions occurred even as performance was being enhanced. Development had proceeded on material substitutes to reduce friction of the air-valve system movable seal, but air leaks during assembly increased. Every time an air leak occurs, it is a major issue in terms of supplying equipment for races on a tight schedule: it takes time to repair, and the crew has to wait for specifications adopted in response until it is almost too late for the race. There were also concerns that an engine might blow out during a race.

The team originally suspected a quality flaw in components on the periphery of the air valve, but could not come to a definite conclusion, so they performed analysis starting at the point where the air leak occurred and found that a minute amount of dust had gotten caught on the movable seal face. Under specifications up to that point, there was no impact even if dust got caught, so material substitution was believed to be the cause. Components were cleaned and then checked prior to assembly, and assembly was done with great care, but it did not solve the issue and small amounts of dust and dirt still got caught.

As a countermeasure, impurities that came from within components and which could not be removed by ordinary cleaning were eliminated by implementing an ultrasonic cleaning system. To eliminate airborne dust and dust from work clothes, a clean room was set up and workers wore anti-dust clothing over their work clothes and anti-dust caps over their hair as they assembled air-valve systems. Movable seal faces, which can be damaged by even a light abrasion, were put on with great care, and the engine assembly process was nerve-racking.

The result was complete prevention of air leaks and the ability to supply more competitive engines.

## 2.3. Supply of Motors Made by Honda

In 2007, the FIA presented a regulation permitting the use of hybrid systems in races starting in 2009, after which it was decided that the motor would be built by the assembly crew.

This was an area in which the assembly crew had no experience, meaning they had to start from the very beginning. Up to that point, the assembly crew had overcome many obstacles and felt that it would surely find a way, but there was much unease with the transition from things one could tangibly observe to something electric, which could not be seen at all.

The crew's education began with the study of motors for mass-produced vehicles. Getting advice from experts on mass-produced motors, the crew began to master this area.

Actually, even the stage of checking the building

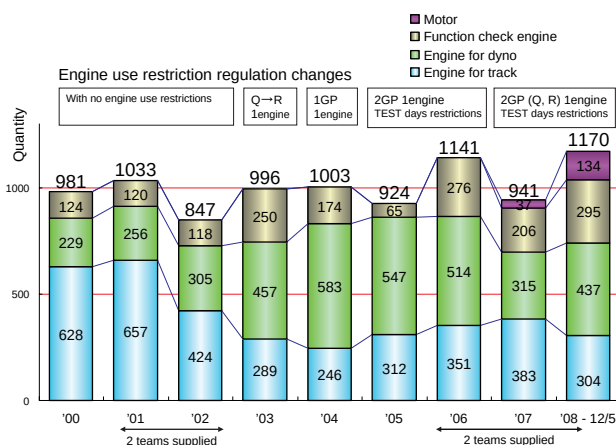


Fig. 1 Record of complete engines and motors supplied

process was of greater difficulty than imagined. Structurally, the job of coiling wire is something that only one worker can do on one motor. It is difficult to divide up tasks as one can with an engine and thereby shorten the production timeline, and when one is planning to supply equipment for race use, one cannot wait until just before the race to decide on the best specifications. Additionally, if some trouble occurs, the equipment would not be on time, and this increased the sense of unease.

Being lightweight and compact while providing high output are absolute conditions for a motor used in racing, so winding technology was required offering a super-high space factor. The issue of greatest priority was to establish a method of winding a coil: specifically, how to wind it so that it would be within the required size.

An examination and winding experiment were begun, but Tries 1-3 could not meet the requirements at all (Fig. 2). The coil end was always too high. At this stage, about 50 hours had been spent on the work. On Try 4, a jig was devised and experimented with, but as it still did not meet requirements, some other solution was necessary. Other attempts were made, such as enhancing the jig or changing the winding process, and on Try 5 a breakthrough seemed to be in sight, but while progress had been made, this still did not meet requirements. With more innovations, the crew finally succeeded in meeting requirements with Try 6. It had taken two months from the start of examination until trial winding.

For the original winding, the crew thought to reduce work time by implementing equipment and winding mechanically, but eventually concluded that meeting the requirements would necessitate a very complex winding method, and as it was just not possible with a machine, it had to be done manually.

Once the winding work was over, the coil ends were molded to fit the coil in the case. At this point, a very big problem came up. During molding, the wires rubbed against each other and shorted out. After all the long hours it took to wind a coil, in the end it was not usable.

The crew understood that the cause was the relationship between the winding method and molding load, but since the work was done manually, it was



Fig. 2 Try 1

impossible to make the way the wires come out match perfectly, so a technique was selected that controlled load during molding.

While the crew somehow managed to succeed, it took many staff hours and there were still concerns about being able to provide the motor on time. After examining many ideas for reducing work time, about 30 types of jigs were created.

Eventually, this effort succeeded in reducing winding work time from about 50 hours to 15 hours, in part because of overall skill enhancement of the workers.

As a result, the crew's goals were in sight for supplying equipment for durability testing, road testing, and all races, and supplying system became highly organized.

Production also got up and running, and the know-how acquired during production for the 2009 winter running tests was a very valuable asset. However, Honda announced it was withdrawing from Formula One and, unfortunately, this motor was never used in a race.

Motor development that had begun with a lot of fumbling and no clear idea of how it would turn out ended up being a source of great confidence and pride for the assembly crew.

#### 2.4. HRD, where Honda Engines were Born

To offset the risk of distance from the engine development base HGT, HRD, the base for onsite engine maintenance (the rebuilding team) and the running test team during Honda's third-era Formula One activities, was established to inherit functions from Honda's second-era Formula One activities and serve as the front line of support for each circuit in the EU. When first launched, the site supplied engines during Japan's long holiday periods (May and August), and subsequently its role expanded, such as making an initial determination of durability and reliability following running tests of new-specification engines, making emergency replacements of rejected lot components, and having materials analysis members onsite. This allowed them to make more detailed analyses and assessments of the situation when malfunctions occurred at the running test site and thus greatly accelerate development. Additionally, when supplying engines to two teams the second time, the scope of the crew's responsibility grew to include all engines for the Super Aguri Formula One Team (SAF) as well as engines for the Honda Racing Formula One Team (HRF) (50% of running engines supplied). The increasing number of engines supplied, along with the need to deal with malfunctions, made it necessary to strengthen and expand the assembly system. Along with this, activities were also transformed by having one person in residence and persons dispatched from Japan taking up long-term residence so that it became their regular work, an arrangement that supported race activities. Engines prepared by the rebuild team were handed over to the site mechanics with the sense of saying, "Please take care of this engine," which, though the words were not actually spoken, bound both sides in a relationship of trust. Every member of the

rebuild team had a sense of pride and self-confidence that the engines they were shipping out were perfect. The engine rebuild specialists dispatched from Japan lived three or four in a home close to HRD during their five- or six-month stay in the UK. In addition, this provided a venue for new members to learn the mindset and spirit of accepting challenges in their day-to-day lives as well as in races, because these people were sharing a home with the veterans several times a year, and it provided the sole place where they could relax while in the UK. It was HRD that prepared the Honda engine that enabled Jenson Button to win the Hungarian Grand Prix in 2006.

## 2.5. Collaboration with Local Members

There were changes to the system in the rebuild field from Honda's second-era to third-era Formula One activities. In Honda's second-era Formula One activities, only persons dispatched from the R&D Center conducted the work, and they were able to work the same way where they were dispatched as in the R&D Center, almost as if the site were an extension of the R&D Center. In the third era, a number of local staff members worked side-by-side with members dispatched from HGT from the time this arrangement was established. The culture and language were different, of course, and the authors remember how difficult it seemed to stay in step with each other. But while fusing our different cultures and launching a system to build equipment together were big challenges for us in conducting race activities in the UK, there was also a great sense of eagerness to do this as a new experiment in Formula One activities.

The local staff members who were hired were typical race engine builders who had only assembled parts out of inventory, and so had no experience with engine development to deal with the development issues from the quality side. By contrast, Japanese crew members acted with a constant sense of responsibility as the final check-persons in every domain (inspection, processing, materials). They also were aware at all times that this place was an R&D center, not an assembly plant, and as such it was up to them to guarantee the quality of the finished engines and it would be the assembly crew's fault when defective components went into their assemblies. When this happened, there were always discussions about why the defective component was not noticed beforehand.

The veterans said, "Get development information from the R&D Center and local information about the circuit, but in any case look closely at the actual engines and components in front of you." There was never any wavering from this principle, which was a tradition handed down from Honda's second-era Formula One activities. Local staff members were partnered with persons from Japan who instructed and guided them to help them develop this way of doing things, so that after several seasons had passed, the work could finally proceed smoothly. Local members were given roles with responsibility and thereby learned a sense of responsibility, so that the two sides came to understand each other better and both could absorb new knowledge

from the other.

In 2006, Honda began supplying engines to two teams for the second time, and it was decided that all SAF engines would come from HRD. Until then, HRD had been in charge of preparing Friday practice engines (P) and race spare engines (RS), but now it would also be in charge of race engines (R), and this would greatly transform the arrangement in which HGT assembled and supplied the R.

Starting that year, all engines from HRD had "Made in UK" stamped on them. This boosted the motivation of local members and was taken as a sure sign of their independence. The authors recall how this established a solid relationship of trust between the two sides in Honda's Formula One endeavors.

## 2.6. The Unknown Story of How the Winning Engine was Prepared

In the latter half of July 2006, to make up work during the summer holidays at HGT, assembly was planned and carried out at HRD on two engines for the Hungarian Grand Prix of August 6-8. Preparation of one engine proceeded smoothly and was completed on schedule, whereas the other was plagued by troubles. During assembly, air started leaking from the valve-train system air-valve seal face and would not stop. Studies were done on the situations deemed likely to cause this (damage to the seal face, the interposition of impurities, deformity and form defects, hardness, etc.), but nothing could be identified. Repairs were made with a great deal of work time spent, for example switching out components from different lots, and the two engines were finally done with little time to spare. A plan was organized to assemble and supply Rd13 engines, a total of three engines including the one assembled at HGT. The HGT engine, with slightly greater output, was mounted on Button's machine, while one of the engines assembled by HRD went on Rubens Gonçalves Barrichello's machine. As for the remaining engine assembled by HRD (the one that had an air leak during the assembly work), it was to be used as the race spare to the disappointment of the local crew, but then the Hungarian Grand Prix opened and Button's engine blew during practice on the second day. The spare engine from HRD was quickly mounted on his machine. Originally slated to start fourth in the qualifying, Button was given a 10-slot penalty for change of engine and had to start in 14th place and would have to work his way up from there. While this would have been fatal under dry conditions at the Hungarian, which makes overtaking difficult, the race day began under wet conditions. Vehicle speed, weather changes, race strategy and veterans' dropping out were among factors that let Button, starting in 14th place, gradually raise his position and ultimately finish the race far ahead of the other vehicles.

At that moment, Honda had won its first third-era Formula One victory. For HRD, winning the race with an engine they had built with one British member and one Japanese member was a great confidence-builder.

### 3. Mechanical Domain

#### 3.1. Supplying Equipment to Two Teams

From the start of Honda's third-era Formula One activities until Honda began supplying more engines to two teams in 2001, the number of staff members increased and, as a result, Honda started supplying two teams with a staff consisting of 13% experienced persons and the rest not experienced. For the mechanics, of course, inexperienced personnel had to be used, but under the guidance of experienced staff from Honda's second-era Formula One activities, these people received practical training in on-site trouble-analysis techniques.

Experience taught us that the ability to evaluate sudden troubles cannot be learned in a very short time, so all sorts of means were considered and put into effect to help the inexperienced staff make up the gap between themselves and the experienced staff. An attempt was made to enhance their knowledge by, for example, reading up on past troubles, conducting simulations of trouble with an actual vehicle in front of them, and having groups of young mechanics practicing FMEA amongst themselves. Sometimes, however, they became overwhelmed by the atmosphere of the site and the sense of urgency and were unable to act.

We felt that the ability to judge and act at a moment's notice in extreme circumstances could not be acquired unless we always had an engine in front of us and could put our hands on it.

Even as their knowledge and competency increased, it did not help at the racetrack unless they had tools, spare parts (including, for example, proven replacement components, in cases where a malfunction occurred with a newly introduced component) and so on.

The veterans often said, "Preparation occupies 90% of work."

The most essential thing needed was the practice of keeping the tools, equipment and components needed at the site in a neat and orderly way so that they could quickly be found when in a hurry and nothing would be missing. This is all very basic. But for the young mechanics, this was where the work began.

The following relates what happened at one event. An engine that had been running smoothly suddenly blew out without warning. The blown engine hurriedly underwent emergency dismantling by two of us, a veteran and myself (Ishihara); when we did primary analysis of the cause, the veteran asked me to pass him a battery-powered impact wrench, but when I picked it up, the battery was dead.

This led to a severe scolding from the veteran. I realized that my negligence in preparation had come to light in that instant. After that incident, the first thing we did at the site was to keep a battery charger ready.

The engines supplied to the race track are supposed to have undergone a very strenuous final check at HGT or HRD, but all engines underwent another engine-specification check at the hands of the mechanics, with each bolt checked for torque, harness wiring checked, etc., time and time again.

Oil-pressure adjustments and air-intake trumpet-length adjustments were made in keeping with the usage environment at the site.

From time to time, components were replaced to deal with troubles in time for an event and the crews constantly tried to extract the maximum performance, durability and reliability in each race.

On the starting grid of the final round, a number of final quality checks on the hardware side of the engine were performed right up to the start of the formation lap, including checks of whether oil, water, fuel and air pressure, air and oil consumption and oil and water temperature were acceptable, whether there were any leaks, whether all cylinders were firing and whether the air/fuel ratio was correct.

This is very hard work, as malfunctions have to be responded to immediately when found.

Sometimes the members were so nervous that their stomachs hurt and they could not eat until the signal changed and the vehicle got off to a trouble-free start.

More than actual race results, the mission of the assembly crew was to make sure the vehicle finished without trouble: for example, during the race, members read data from the telemetry system and prepared for an emergency pit stop if any abnormalities occurred.

#### 3.2. Kitching

On the job at the racetrack, it was necessary to make sure that all mechanics were correctly producing the same output. This is referred to as "kintaroame," which is a kind of candy formed with an image in it. The association implies that it was vital, no matter who cuts it open and where they cut it, that the result will be the same.

The two race engines provided for the two drivers were lined up and arranged in detail right down to the thickness, position, direction and binding force of the wire harness and the tie-wrap that anchors the auxiliary components (Fig. 3).

Deciding on assembly work procedures and specifications when there are no blueprint instructions is, in large part, dependent on the experience of the mechanics.

This is because the heat, vibration and stress on



Fig. 3 Completed engine

components are so much more severe than is the case with mass-produced vehicles. Particularly during the summer races when it was so hot, the need to take countermeasures arose often, and when malfunctions occurred, there was a series of revisions of work procedures and specifications in keeping with changes in the environment so that crews on the site could determine the causes of the malfunctions and make the correct judgment on how to repair them.

Most particularly, with work procedures and specifications for engines built to new specifications, the crew, racking their brains, reflected procedures taken against past troubles, then verified these procedures in shake-downs and running tests.

Work procedures and specifications that were found to be reliable were then compiled in the form of a manual, including photos taken with a digital camera to illustrate things that are difficult to explain with text alone.

Surely, this was a case of “seeing is believing.”

The crew furthermore created a checklist so that nothing would escape the attention of all the personnel. As the years went by, the check items became subdivided, so that by 2008 there were 120 items.

This final check process before shipping equipment out is referred to as “kitching,” a word that is completely unique to the Honda Formula One world. This word goes all the way back to the era when the company participated in Formula Two racing in the 1980s. At the time, some veterans did not have enough time before a race to send an engine back to the R&D Center, so they did an emergency rebuild in the kitchen of the local company housing unit in England before sending it on to the race track, and the process was subsequently named after the rebuild site.

To be a mechanic, first of all one had to be able to do kitching correctly, and this became the gateway to success in becoming a mechanic.

During the third-era Honda Formula One activities, new mechanics were strongly advised by the veterans: “As a mechanic, you are carrying a big Honda sign on your back. As a representative of the assembly process, act in ways that will not make us ashamed.” Those words were bracing whenever I heard them. I felt as if I were an Olympic athlete wearing the rising sun of Japan on my back.

“Go for it! You can do it! We’ll be rooting for you on TV!”

As the vehicle set out from HRD to the circuit, all members came out to send it off. This was always a happy moment.

Formula One is very much a part of European culture and an event of its noble society. We took on this technical battle as representatives of Honda from Japan all the way in the Far East, with a different language and culture, and as representatives of Japan itself.

### 3.3. Onsite Engine Dismantling

During the engine startup check on preparation day during the 2005 Canadian Grand Prix, a lot of air erupted

from the oil tank freezer. Both the P1 pressure (gas cylinder pressure) and the P2 pressure (engine supply pressure after regulator pressure adjustment) started falling and would not stop. When the P2 sub-line was removed to identify the location of the leak, the leaking stopped.

The leak was from the engine itself.

With no time to think, the place erupted into an uproar, with some people rushing to change out the engine to be in time for the vehicle inspection, and others acting decisively to hurry and open the cam cover to analyze the cause.

What the engine showed when it was dismantled was that a valve cotter had become embedded in a pneumatic valve return system (PVRS) piston and the seal ring was protruding very slightly beyond the chamber, causing the air leak. Results of analysis confirmed a malfunction in the taper angle of the cotter contact face of the PVRS piston, creating a looser taper angle than usual so that the cotter went deeper.

In this state, it was impossible to determine whether the trouble was caused by a quality defect.

As such, all the crew could do was check the interior of all five remaining engines. This would take as much as five hours per engine, and everyone was involved, including those who had come to hand over their work to substitute members.

Ordinarily, if one were to open the cover and remove everything down to the cam, the conventional wisdom would be to run the engine on a bench and check to see if there are any oil leaks or other abnormalities. But this kind of work cannot be done at the racetrack, and neither can the crew afford any errors. Nonetheless, they finished in time for the qualifying round, during which the team earned its first pole position in the season, giving the crew a taste of having accomplished something great. With the extreme tension lifted from their shoulders, the team mechanics shook our hands and congratulated us with a “Good job! Good job!”

Naturally, it would be better if there were no problems, but this experience in particular helped develop fearless race mechanics and was also reflected in HGT’s engine development blueprints, which enhanced durability and reliability. Responding to phenomena as they occur at the actual site, checking actual articles and getting to know the actual facts are essential to preventing the same trouble from happening again; this is the practice we call the “three-reality principles” in Honda. The crew relayed to Japan what they were thinking at the actual site and what was necessary, and passed that information on to Japan.

We understood the significance of mechanics because, as in this case, “if there is no word from the actual site, nothing will change.”

### 3.4. Adding an Air Pump

An air-pump system to supply air valves was added in 2003 as a way of reducing friction in the valve-train system, and this system was a source of many troubles for site mechanics.

The team requested that the volume of the air cylinder mounted on the vehicle be reduced. A mounted air cylinder would certainly seem to have an impact on aerodynamics, and making it any larger would be challenging.

An air pump was the way to solve the problem in order to continue supplying a limitless amount of air, which is consumed in such great volume.

It was a wonderful idea, as it would also free the mechanics from having to fill the cylinder with air onsite. However, at the start of development much more work was awaiting the crew than they had experienced up to that point. There was no way it was going to become easier.

The crew mounted a small compression pump on the engine and used engine oil to lubricate it. It looked just as if a radio-controlled car's engine were attached.

At first during development, it was one malfunction after another, and there was not a single day when it ran properly and without any trouble.

"The air pressure seems off. How's the regulator doing? Is the pump working? How about the hose?" The work consisted of a lot of urgent evaluations, because if the air supply were cut off, the engine would soon blow.

Simultaneously with air being supplied from the pump, the engine oil used as lubricant forms oil sludge, blocking the air channel. The filter intended to remove this became clogged from the great volume of oil sludge, so the air channel in the engine front cover also got blocked.

For the front cover, the crew attached a brush to an electric drill to clean out the air channel, but this failed to remove the blockage, so carburetor cleaner was blown in from the air-pump intake for 10 seconds and left to sit for five minutes before one minute of firing, a process that was then repeated a second time. This was done after both morning and afternoon runs. Components that had to be dismantled, moreover, were cleaned inside the trailer. For secrecy, this could not be done in the garage.

The process of cleaning out the acrid, black, slimy sludge lasted late into the night.

During initial development, filters had to be changed and channels cleaned out, and there was no way to avoid stopping the vehicle so much that it impacted not only the race distance but even vehicle testing.

We still cannot forget the team leaders gathering around and peering in, then giving us a cold British stare.

It reminded us that as mechanics, we are the front line and must bear the brunt of any troubles. As the engineers worked in the trailer each night under pressure to organize running data, they were close to that strong sludge odor, but nobody said, "Stop it, it smells terrible!" Everybody was aware of the situation and they put up with it together.

Naturally, once we all got the idea that "we've got to do something about this," it had a positive effect on later enhancements. Measures taken included reducing the temperature of the air blown in to a point where oil

sludge was less likely to form, and also managing the clearance between pistons and cylinders as a measure against oil outflow.

### 3.5. Adding a Quick-Shift Gearbox

In 2003, the first thing the development supervisor said was, "Let's build the world's greatest gearbox," which was the start of a project to reduce lap times by developing an original new mechanism called a quick shift, which theoretically had no time lag during shifting. The technology of the system was later transferred to BAR, initiating the project to put it to use in races.

The development team and we were braced to do this, but at the time the basis for achieving such technology had not been established. Those of us who had specialized in developing and supplying Formula One engines were also dealing with gearbox development for the first time, and with no experience in these matters, we were starting from zero. It was also a turning point, after which the scope of our responsibilities expanded.

The British American Racing (BAR) team leadership expressed disapproval at the start of development, as they questioned what role Honda would be able to play in joint development of a gearbox and suggested they had nothing to learn from us. There was a reason for this attitude: in the year before the command applied, we received a chilly response when a malfunction developed on the driving site in a narrow-shift gear mechanism that had been suggested by HGT. Taking this experience into account, we responded this time with greater passion and speed.

A quick-shift system allows double engagement of gears: the gear being driven and the next gear to which the driver is changing. Because of this, during shifting there is no torque drop. The following year the crew proceeded to actual driving evaluation, when BAR, which got to know this mechanism on actual vehicles, had completely changed their attitude. Many engineers came to look at how the shift mechanism moved in the first equipment.

All of them said, "That's crazy," and left. At the initial running test, after a pit stop, we saw engineers and mechanics coming by, even climbing up the course-side fence behind the pit, to hear the sound of gears changing.

In reality, however, a series of severe development issues occurred. The crew tried all the countermeasures they could onsite on both the control soft side and hard side (making manual modifications to change the form), but each time the same phenomenon occurred at the same travel distance (35 km).

Although the system had passed the bench tests, there was now a baffling series of phenomena. From this situation, the crew proceeded with the priority of enhancing durability and reliability, with HRD rearranging components that HGT had sent out, but every time the logistics took until just before test time. Everyone worked late into the night to conduct stopgap solutions and change out the gearbox at the running test site as we endeavored to somehow stay within the schedule.

Gradually we could see the replacement parts taking effect, and with the start of long runs, drivers began making such positive comments as:

“Shifting was seamless, with no sense of reaching a plateau. I could even shift up while cornering and the rear did not show any turbulence, and each time I shifted up it shrank the distance between me and the car in front.” The new system was proven to reduce lap times by 0.2 sec/lap compared to a standard gearbox. Unfortunately, during the 2004 season the system was unable to meet the 500 km durability requirement, so it was introduced the following year, in the opening race of 2005, when it became the first such technology used in a race. And with that, the world’s greatest gearbox was complete. At the circuits, other teams refer to this as seamless shifting.

In any case, after accepting all the facts, the assembly team had accomplished a transfer of work responsibilities to BAR, from creating systems and environments for supplying test equipment to running race operations.

### 3.6. Adding a J Valve

The J valve system added in 2005 was developed to reduce valve-train system friction.

In the structure used up until that time, one-way valves were placed in the air chambers that work as valve springs at each of the various entries/exits, so that even if in the worst case the air supply died, the valve would not fall from its own weight. These one-way valves were eliminated, however, and each air chamber was given an orifice to create a continuous passage, so that if air leaked from one air chamber, it would interfere with the valves of all cylinders. The crew learned that the engine quality could not be assured with this new system as in the past.

The engine assembly method had also changed, but above all else the mechanics put their energy into transportation methods and methods of operation from onsite storage to engine startup, and most especially on a technique of lubricating the valve stem with oil.

During engine startup there was concern about the valve stem getting burned, and what caused the most hardship of all was how to control the amount of oil inside the engine, which the crew could not see.

During operation, the system banged against the wall and we were not at all sure it would be OK.

- What is the minimum pressure needed to keep valves from falling from their own weight during transportation?
- What is the minimum pressure for valves to track movement of the camshaft when the crank is being turned by hand?
- What are the temperature and pressure that would make air leaks unlikely based on characteristics of the PVRs piston seal?
- Can oil be purged from air lines if collected and retained in air chambers?
- What capacity is necessary in large, high-pressure air cylinders?
- Can the engine be shipped by airplane with a large, high-pressure air cylinder attached?

- How can one check the initial lubrication of valve stems?
- These worries were dispelled by testing each item one-by-one.

In all cases, while engines were being assembled at HGT, sent to the circuit and returned to HGT again, we constantly attended to the engines and collected data on them and finally determined the requirements.

We proceeded with particular caution when the technology made its racing debut in 2005, and the J valve proved it had reached completion on the race track operations side, and it later became the standard.

We continued to collect data after that, to the point where, by 2008, we had successfully simplified the technology on the equipment and operations side in large part.

The technology could then be normally used on an engine without any of the anxiety as in the early days of development. The supervisor of J valve development at the time said something I never forgot:

“Whether the J valve will be successful or not all depends on how it’s used on the race track. I expect a lot, especially of the mechanics.”

### 3.7. Extending Engine Mileage

Previously it was possible to change engines on Friday, Saturday and Sunday, but regulations starting in 2004 required that engine mileage be extended and that only one engine be used per race. The mileage requirement was further extended in 2005, so that a single engine had to be used in two races, starting with practice. The distance each engine was used went from 300 km to 800 km to 1500 km. Instead of simply extending the mileage of an engine with the same specifications, the engine framework specifications should be altered in the course of steady development to achieve both durability and reliability on the one hand, and performance on the other.

The penalties for changing engines were severe: if the engine was changed because of trouble occurring within the required usage distance, the driver would be penalized 10 slots if it were before the qualifying, and if it were changed after the qualifying, the driver would have to start in last place.

Before the penalties were imposed, if trouble occurred, the team could weigh the time it would take to analyze and repair the defect against the time it would take to change the engine, and choose whichever was faster.

If done quickly, an engine can be changed in 30 minutes.

Of course, the pit was set up to deal with such situations. Nearly all the components concerned with the engine, including radiators, oil coolers, oil tanks, exhaust pipes, clutches and hydraulics systems, were installed in the pit.

At each circuit, there were always practice engines, qualifying engines and race engines for two drivers, as well as three spare engines and one engine for a training car. This meant that there were at least 10 engines in the garage, and of course not all of them could fit. On

older circuits in particular, garage space is limited and it is a very challenging work environment just to load and unload engines from their special transportation boxes.

In a complete turnabout, the change of regulations eliminated the work of changing engines every day as well as reducing the total number of engines, so everyone thought there would be less work to do.

Everyone was wrong.

Now the crew had to check the inside of the cylinders each day after the engine's run, instead of only when an abnormality occurred. A fiberscope was used to detect any piston scuffing inside the cylinder, which was determined by the appearance of the sleeve (Fig. 4).

Another important check item was to detect any pitting in the spline of the input shaft that couples the crank tail-end to the clutch housing.

If any pitting were discovered on the spline on the crank side, it was polished away. If this is overlooked or ignored, it can start a process that results in the crank breaking and metal burning as the engine fails to maintain oil pressure.

Removing pitting marks with a compound and diamond rasp is a difficult job because the crank is so hard. The question of whether an engine can be saved is a heavy burden on the mechanic in charge.

Flushing with oil was also done after each event. The objective is to get rid of any degraded oil still clinging to the conrod pin metal and main journal metal. This job is essential after each race, because experience has shown that engines with stagnant oil in them for an extended time will occasionally suffer metal burning, either in bench tests or on the circuit.

It was also unavoidable that components would have to be changed that did not assure sufficient durability.

The crew had to use every possible means to meet the high hurdle of 1500 km.

The engine truly was a lot of work.

At the circuit, although ideally there should be no more of these jobs to do, they became a regular feature.

Maintenance of an engine to keep it in continued use depends in many ways on the mechanic's competence and experience, and if just one thing is overlooked, it



Fig. 4 Checking inside of engine

dooms the vehicle to withdrawal from a race.

The assembly crew discussed this a lot with the design, research and electrical staff. Looking back now, it seems not so much a discussion as a pathetic plea from us to them to "Please fix this engine right away, and please get it out to the track so we can use it with confidence." A major part of this plea was the fact that each race was contested with a special kind of pressure: the driver's life was in our hands.

Even aside from the need for continuous maintenance, the requirement of two races for each engine put great pressure on mechanics in other ways.

It was no longer simple to decide whether or not to change the engine, and now the mechanics had to analyze malfunctions and do repair work with greater accuracy and speed than ever before.

Accomplishing this created a need for tools with greater functionality and a wider variety of components than before.

The amount of equipment and components brought onsite increased to the point where the crew could assemble an entire engine from them.

Of course, there were also enhancements in maintainability and work efficiency.

The veterans were fond of telling us, "The race does not wait; this is a battle with time," and in fact we were often forced into such situations.

In a sense, the changes in regulations created a challenge to the mechanics to provide quality assurance of the engines.

### 3.8. Launch of SAF

At the end of 2005 it was decided to start supplying engines to SAF. Five members of the first crew in charge of this area entered the UK on January 12 of the following year. At the SAF factory in which they settled, the rising sun flag of Japan was a big landmark in the rural area of Leafield west of Oxford, England.

This day was the start of a big challenge.

When the crew arrived, SAF had fewer than 20 employees and no vehicles, equipment or components. That was the first impression: they don't have anything. This was quite different from supplying engines to an existing, already organized team, so the crew had to do double duty by also launching a team.

Their first goal was to get two vehicles to the final round grid in the first race of the season. As the crew gave instructions, everything had to start from the very beginning: preparing tools and equipment spare parts; changing the engine auxiliary components (replacing BAR specifications with SAF's); integrating engine operating rules (post-arrival, return shipping methods, warm up, oil management, pre-mounting status, etc.); engine startup and running procedures; distance-controlled components; and so on.

Everything started with dialogue.

Having set foot here, the first crew continued working patiently, keeping its feelings under control.

On January 17, the initial vehicle (the base was an old Arrows A23 built to 2002 specifications, which had

been out of the Formula One world for an unusual four years) was brought in, after which the team modified the monocoque to allow Honda's engine to be mounted and modified the chassis to enable it to pass the FIA's collision requirements. Then, equipment was introduced and physical production began.

Ten mechanics were also hired, so that on January 30, vehicle assembly began. Everyone worked on production, which was all done by hand. There were no differences among members, and even the chief designer and technical director were put to work. These people responded well, and we had no troubles in terms of communication.

Everybody was helping each other with their roles and responsibilities, without anyone getting in each other's way. It was all positive and forward-looking, and with everyone cooperating, there was a strong sense of teamwork.

Day 32; Shake-down of initial vehicle (SA05-05)

Day 39; Barcelona joint testing (SA05-05): time was not an issue here, but the vehicle ran 590 km.

Day 58; First race, practice stage, two vehicles began running

Day 59; Got through qualifying stage with 20th (SAT) and 21st place (IDE)

Day 60; Two vehicles line up in the final round grid

Having met the first target must have given the crew a sense of accomplishment, but they were actually quite cool about it. It seemed as if they took it for granted that we would be in time for the opening race. Those two months seemed to go by very slowly, but this was just the starting line of the season.

Although the team did not bring home any trophies, it attracted increasing attention. With each race, the look on team members' faces became sterner. There should be no failures and no delays, so their expressions changed.

As the races went by, we ran out of spare parts and team vehicles had to retire more often, emphasizing the fact that we were not making progress on the vehicle. Starting from Rd12, we added the Honda gearbox (quick-shift) and gave technical instruction.

Along with that, we changed the suspension and the vehicles advanced significantly, which enhanced vehicle performance and provided valuable racetrack experience. Prior to qualifying rounds, gear ratios were changed on three vehicles, including the training car. This work concerned a gearbox with a new mechanism, and the SAF mechanics did not have any onsite experience changing the new mechanism. Two hours before the qualifying, the three vehicles were lined up for presentation, and the team had acquired its first experience working in an actual race. We recognized again the importance of maintainability and reflecting enhancements. From there, we began special training to give the team mechanics more independence.

In 2006, SAF was born as a new team and competed in all Formula One races.

Everyone who set foot in Leaffield that year had a part in this dream.

### 3.9. KERS Development

Even the Formula One world is expected to care about the environment, and it was decided to change the regulations greatly in 2009.

That is when the kinetic energy recovery system (KERS) was introduced. It became a matter of some urgency to develop a hybrid system, a Formula One version of the INSIGHT, as it were. The reason hybrid cars are considered so good for the environment is because of their good fuel economy. And in a race, of course, competitive fuel economy is a huge advantage strategically.

The regulations, furthermore, allowed output of up to 60 kW of electric power charged from the motor during deceleration, with engine assist of up to 400 kJ of energy released per lap; functionalities like increasing maximum speed and enhancing acceleration coming out of corners were expected to reduce lap times. This created a need to develop a lightweight, compact and efficient system, and Honda did all the development of the motor, PCU and battery in-house. Having this development done in-house was of particular importance to the mechanics as they headed out to the racetrack.

They would absolutely need a thorough familiarity with this new system in order to gain the knowledge and technology to be able to safely and flexibly deal with malfunctions on the circuit.

If one were to use a purchased item, there would be no way to know what is inside. In other words, a purchased item is like a black box, and there is nothing more to do with it.

In contrast, the crew had no excuse for not understanding something developed at HGT. Fortunately, the motor was built by the assembly department.

At first glance, no one looking at this motor measuring a mere 105 mm x  $\phi$ 100 mm would think that it creates even as much output as one FIT motor.

One can easily imagine that developing this motor took much more than the average effort.

Everyone on the crew started as a novice in terms of motor assembly.

It also required a very complex way of winding completely different from a mass-produced motor, and was only completed with a great deal of trial and error.

UN rules on handling batteries proved to be a great obstacle.

Using a battery lithium ion, individual cells were combined into modules, which were then combined into packs. The mechanics thought it would be the packs that they received at the site.

But what was sent from Japan to HRF in England was a large number of individual cells and a welding tool to join them together.

It takes at least three months to get permission under UN rules to ship cell modules and packs, and a new application is necessary each time specifications change. This would be fatal in the Formula One world, which has very short development spans, and we had never felt how far Japan was from England until that point.

Our goal, nonetheless, was to never give up, and to

be the first to do this task successfully, and the only way to do that was to have the mechanics do the welding in England. Still, the welding effort had to start from zero.

A mechanic had to learn the special welding technique in a short time and then bring it to England, where the welding was done in a corner of the HRF warehouse. As we struggled with this we paid close attention to safety.

Each cell has a slight charge to stabilize it, and there was some concern that during assembly, an error could electrocute the person. Of course, the people doing the welding first took a course in electrical safety, and even went to Honda's Suzuka Factory, where hybrid cars are mass-produced, to observe there. To be honest, we thought that electricity was so frightening because it is invisible to the eye, but as our knowledge grew, we mastered ways of protecting ourselves from danger.

The mechanics undertook to identify 187 malfunctions and take care of pending items that could occur by the time the motor, PCU and battery were mounted to the vehicle.

Not only were there assembly malfunctions from parts touching each other, but assembly work procedures and specifications were decided where there had been no blueprints or instructions relating to reliability and work characteristics, from putting on the harness to assembly procedures.

To ensure safe operation at the site, everyone discussed what was safe and what was dangerous, based on system diagrams. The team checked each work process, starting with the preparations prior to engine startup and continuing through post-cruise dismantling (Fig. 5).

As this was going on, the Internet started circulating news and photos of a mechanic with BMW Sauber getting a shock on a circuit during a test driving. It shook up everyone and showed that there was disaster lurking in unexpected places.

Ultimately, it reminded us that, to protect ourselves, each person had to be aware of his own safety.

The result was mechanics with a wide body of knowledge and skills and an awareness of safety in areas completely unlike the past.



Fig. 5 Checking KERS system

In April 2008, actual driving development began with a shake-down test at Santa Pod in the UK. It was hard going, since there was a series of issues we had never experienced before, but with this event the crew succeeded with a KERS road trial for the first time in Formula One.

There were subsequently two more shake-downs and a driving on the Jerez circuit in Spain, and in November the crew was back in Santa Pod for the fourth development shake-down, and during these events we overcame the various issues.

We faced phenomena such as being unable to pre-charge or unable to connect the main conductor, the cause of which turned out to be a broken contact point melting damage prevention circuit when connecting the main conductor incorporated into the high-voltage circuit in the battery. Because the battery of the third development lot was stored under the driver's seat, we tried connecting the main conductor manually from the outside by having the driver step out of the monocoque and removing the seat each time the engine was started. This connection procedure was complicated and required much time.

In Formula One development, which constantly requires more speed, no matter how tiny the part may appear, this was indeed a serious trouble.

Moreover, the effect of electrical noise on the communications system prevented the technology from providing full output, and there was nothing more that onsite analysis could do in this state. To give priority to analysis of the electrical noise, the team canceled their participation in the next Paul Ricard Test, and the vehicle was hurriedly sent from England to HGT. Of course, the mechanics also went home with regret in their hearts.

At Spain's Jerez circuit the vehicle made a new start, the driver's evaluation stating, "I still have a lot to learn about KERS, but I was impressed by how amazingly fast I approached the hairpin when the assist kicked in. It makes non-assisted acceleration from the engine alone feel as if we are carrying a heavy weight."

The fourth development lot system, which was more lightweight and compact, also suffered frequent issues with communications line noise, and the mechanics providing support at HGT took a number of countermeasures, like adding a condenser to the PCU, adding ferrite and enhancing locations with defective grounding.

It was the first time for assembly team members to touch the PCU. In the meantime, HRF actually performed more than 100 engine startups and put their energy into identifying the source of the electrical noise. The PCU on which measures had been taken reached the site just barely in time. The electrical noise had been eliminated.

Then came the December 5, 2008 surprise announcement that Honda was pulling out of Formula One.

That marked the end of a solitary 12-month battle the mechanics had waged in anticipation of a new era.

## 4. Afterword

Looking back on nine years of activities, Honda's third era of Formula One started with the development and supply of engines. The effort subsequently responded to diverse needs, from meeting development requirements to developing a gearbox, conducting vehicle running tests, developing KERS and, moreover, launching a private team. Although Honda's withdrawal from Formula One ended an era and we were never able to ascertain the competitive strength of the 2009 vehicle, we believe that the racing spirit cultivated here will one day shine again in a new age of racing.

While we did not unfortunately leave a great record of race success, the guidance given by our veterans helped to pass down their mindset. We are moreover thankful for the cooperation of all departments concerned with development that helped us to carry out our duties.

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