Transition of Regulation and Technology in Formula One

Hiromasa TANAKA*

ABSTRACT

The Formula One regulations are established with consideration of fairness, competition, safety, sustainability, and entertainment value.

In order to ensure free technological competition, the technical rules of Formula One, under which constructors are obliged to compete using original vehicles, are essentially free, other than specifying minimum basic items.

From the beginning of the 1990s to 2009, despite continuous changes in the regulations to increase vehicle performance control and safety, lap times improved almost every year due to the development of technologies that exceeded regulation stipulations. As a result of these battles, the letter count of the Formula One technical regulations has increased more than three-fold over 19 years.

Detailed technological development spanning a broad range of elements and involving the use of computers, in addition to a comprehensive management approach that brings these elements together, are essential to the Formula One of the 2000s. In recent years in particular, Formula One has responded to rapid social change, for example with measures to cut costs in line with worsening global economic conditions, and the development of environmental technologies, as exemplified by responses to global warming, in addition to measures to highlight competition – the essence of Formula One racing – and to increase the spectacular nature of the races. This is a period in which Formula One is reflecting upon the very meaning of its existence.

1. Introduction

Teams entered in the Formula One World Championships are basically required to race their own original vehicles, and are termed “constructors.” Formula One racing, which commenced in 1950, encompasses both a driver’s championship, in which drivers compete to determine who is the world’s fastest, and since 1958 a constructor’s championship, in which constructors compete to determine which of their vehicles is the world’s fastest. However, the production of engines presents a considerable challenge to any participant other than an automaker or a specialized engine manufacturer that possess specialized technologies. In the case of engines, Formula One regulations permit acquisition or purchase from an external engine constructor. Therefore, in the naming of teams, the name of the chassis comes before the name of the engine, and the constructors’ title is awarded only to the chassis.

In the racing world, the term “works” refers to the fact that a maker itself manufactures the racing cars, racing engines, and the like, or manages the team. Divided into first, second, and third eras, Honda’s Formula One activities were organized as follows:

(1) First era (1964-1968): Raced under the Honda name as a full works team, including engine construction, chassis construction, and team management
(2) Second era (1983-1992): Supplied works engines as an engine constructor to chassis constructors including Spirit, Williams, Lotus, McLaren, and Tyrell
(3) Third era (2000-2008):
- 2000-2005: Supplied works engines to and conducted joint chassis development with the chassis constructor British American Racing (BAR); raced as BAR Honda
- 2006-2008: Raced as Honda Racing F1 Team (HRF1) as a full works team, including engine construction, chassis construction, and team management

In parallel with these activities, Honda also supplied engines in 2001 and 2002 to Jordan Grand Prix, and from 2006 to 2008 to SUPER AGURI F1 TEAM (SAF1).

For almost the entire period between Honda’s second and third Formula One eras, from 1994-2000, the company supported technical development efforts by MUGEN (now M-TEC), a company that supplied engines as an engine constructor, and was involved in Formula One as part of MUGEN-Honda.

This paper will first discuss the characteristics of the

* Automobile R&D Center

Formula One regulations, and will then go on to consider the main changes in Formula One regulations and technologies employed from the beginning of the 1990s, the last phase of Honda's second Formula One era, to 2008, the last year of the company's third Formula One era. It will also look at the changes in Formula One regulations and technologies up to 2009, for which Honda engaged in vehicle development, but ultimately did not compete due to the company's withdrawal from Formula One.

2. Characteristics of Formula One Regulations

Formula One regulations are based on the FIA International Sporting Code, which provides shared rules for all motor sports, and incorporate sporting regulations and technical regulations unique to Formula One championship[(1)]. The sections below will discuss the characteristics of these regulations, with a focus on technical regulations that directly affect technical development for Formula One.

2.1. Basic Principles and Structural Conflicts

Formula One involves competition between vehicles built from scratch by constructors. To help ensure competition, absolute prohibitions and mandatory observances have been minimized in the technical regulations, and constructors are free to approach any point not explicitly covered in the regulations as they choose. For example, there are no rules concerning the wheel base, and constructors may employ a wheel base of any length. One can associate the "Formula" in Formula One with the minimum standards in the regulations.

This basic concept is actually the antithesis of the concept of production car racing. In production car racing, a homologated mass production vehicle that has satisfied specific requirements regarding the number of units produced is used as a base, and only modifications that are specified in the regulations can be made to the vehicle.

Formula One racing is a contest of speed, and the performance of the vehicles therefore tends to improve year by year. To help ensure that the performance of the vehicles does not exceed the limits of the capacity of the circuit safety facilities such as run-off areas and guard rails, the rules of technical regulations are continuously enhanced in order to increase the safety of the vehicles themselves and to impose restrictions on vehicle performance. However, in order to take victory in a fierce competition, each team pursues technical development to the very limits of the regulations. Clear standards and accurate methods of judgment are therefore necessary for regulations designed to help enable fair and consistent judgment of the outcomes of this competition.

To this end, the regulations themselves should be finely subdivided and highly detailed. However, once highly detailed regulations have been formulated, even a slight deviation from the narrow scope they define enables developers to attain a freedom in their development just because it is not subject to the regulations. As a result of teams pursuing development of this type that attempts to sidestep the regulations, and of the continuing formulation of increasingly detailed regulations in an attempt to control it, the Formula One technical regulations increased in volume from approximately 40000 letters covering 65 items in 16 chapters in 1990 to approximately 86000 letters covering 140 items in 21 chapters in 2000, the first year of Honda's third Formula One era. By 2008, the final year of the company's third Formula One era, this had risen to approximately 122000 letters covering 157 items in 21 chapters.

A description of the detailed mechanism of formulation and amendment of Formula One regulations can be found in another paper[(1)], but in terms of Formula One history, when a regulation has been clearly deficient, the principle has been that the relevant item will only become prohibited following the publication of a formal codicil and the completion of the amendment procedures, and until that time teams are able to use it to their advantage. However, the right to specify interpretations within a scope in which no modification of the text of the regulations is necessary belongs to the Federation Internationale de l'Automobile (FIA) at any time, and the organization issues technical instructions called Technical Directives (TD) to all Formula One teams as necessary. Other than this, the FIA also has the authority to permit the Stewards of the Meeting to exclude vehicles that are considered dangerous from race events. Objections to a judgment at a race event may be presented before the International Court of Appeal (I.C.A.), the final court of appeal for motor sports.

2.2. Example of a Conflicting Interpretation

The 2005 regulations specified the following points: First, the regulations defined vehicle weight as the weight of the vehicle including the weight of the driver in full racing apparel, but did not indicate whether or not the fuel was included in this figure. The regulations further specified that the weight of the vehicle was to be no less than 605 kg during the qualifying practice session, and no less than 600 kg at all other times during a race event. Ballasts could be employed to reach the minimum weight, but the regulations specified that a ballast should be secured in a manner that necessitated the use of tools for its removal, and that it should be possible to affix seals if deemed necessary. Further, during the race, no substance may be added to the vehicle other than fuel and compressed gases.

Since 1994, it has been customary in Formula One to verify the weight of the vehicle with the fuel removed in the car inspection following the completion of the race, in order to help stop teams from attaining an advantage by running under the minimum weight during the race and bringing the vehicle up to the minimum weight after the race by adding fuel in the closing stages of the race. However, there was insufficient consensus between the FIA and the teams regarding the level to which fuel should be removed. In actual fact, to completely remove all fuel from the fuel system would necessitate dismantling part of the engine, which was unrealistic on the circuit. The teams therefore considered that under normal circumstances it was acceptable to include the remaining unusable fuel in the vehicle weight.

However, an issue arose concerning two BAR Honda vehicles that took 3rd and 5th place in the San Marino Grand Prix, the 4th round of the 2005 season. At the time, BAR Honda vehicles employed a sub fuel tank to help maintain a stable fuel supply pressure. The configuration was such that the fuel in the sub fuel tank could not be easily removed using ordinary methods. It was reported that when one of the vehicles was reweighed during the car inspection following the race after all fuel from the sub fuel tank and all remaining fuel from the main fuel tank had been drained, it was found to be 5.4 kg under the regulation minimum weight of 600 kg. Based on the report of the outcome of the car inspection, the Stewards of the Meeting interviewed the people concerned, finally upholding the original race result. However, the FIA brought an objection to the I.C.A.

The I.C.A. considered that it could not be physically proven that the vehicle had not been run during the race below the 600 kg minimum vehicle weight, and that insufficient evidence was provided by the combination of data and theory. In addition, it upheld the interpretation that because the use of fuel as ballast did not correspond to the rules concerning ballast, it could not be allowed. However, if this interpretation of ballast was followed, then oils and cooling water would also not be included in the minimum weight of the vehicle. In actual fact, however, vehicles are weighed following races containing oils and cooling water. Because addition of oils or cooling water during the race is not allowed, they cannot be used to bring the vehicle up to the minimum weight, and they are therefore customarily considered to be included in the vehicle weight.

The final verdict of the I.C.A. was that while it could not be proven that the team had deliberately set out to commit fraud, the team's actions at the time that the fuel tank was drained for inspection, and their failure to request a clarification of the interpretation of the relevant regulation in advance, demonstrated negligence on their part. The two BAR Honda vehicles were disqualified from the San Marino event and the team was suspended from the next two events in the championship. The team was also suspended for a further period of six months, but this penalty was suspended for one year.

In Formula One considered as a sport, whether or not an inspection is conducted, competitors are regarded as having sworn that their vehicles are in compliance with regulations when they participate in a race. The onus of proving this rests on the teams. The authority to interpret the regulations is stipulated as resting with the FIA, the entity that is authorized to conduct the competition, and this authority should be respected. The author therefore has no intention of arguing with the I.C.A. ruling. However, a clause was added to Section 6.6. of the technical regulations in 2008 stipulating that all competitors should provide a means of removing all fuel from the vehicle, and this can be seen as a means of more certainly heading off any disagreement over the interpretation of the regulation.

3. Changes in Formula One Regulations

This section will discuss changes in Formula One regulations and technologies (Table 1), while providing some examples of development within each area of technology. For details of specific technologies, please refer to the relevant paper in this special issue of the Technical Review.

3.1. Engine and Powerplant

Regulations concerning the engine have been continuously revised in order to limit the performance of Formula One vehicles. In 1995, the previous maximum displacement of 3500 cm^3 was reduced to 3000 cm^3, and this figure was further reduced to 2400 cm^3 from 2006. Until 1999, the maximum number of cylinders that could be employed was twelve. However, as a result of a technical trend that valued the overall balance of the vehicle over the performance of engine unit teams gradually moved towards the use of ten cylinders, and by the time the regulations specified ten as the maximum number of cylinders in 2000, all Formula One engines already employed this number of cylinders. In 2006, together with the reduction in maximum engine displacement, the maximum number of cylinders was reduced to eight.

While it cannot necessarily be considered ideal from the perspective of seeking increased engine power, from the mid-1990s teams proceeded to increase the temperature of the cooling water in their engines, in order to reduce the aerodynamic drag generated at the openings for the cooling system. In order to put a stop to this trend, from 1999 the regulations specified a maximum cooling water pressure of 3.75 bar.

Maximum engine speed reached about 20000 rpm in 2006. While it had previously not been treated in the regulations, from 2007 maximum engine speed was limited to 19000 rpm, and from 2009 to no more than 18000 rpm. To help enable the vehicles to be run faster at a restricted engine speed, there was a trend towards an increased frequency of use of the high engine speed range, and this made developments aimed at increasing durability even more necessary.

In order to reduce costs by limiting changes to engine specifications and the number of engines used in a year, a (long mileage) regulation was introduced stipulating a minimum use distance for the engine. Previously, constant engine changes had been allowed during a three-day race event, but in 2004, regulations obliged teams to use one engine per race event. The following year, more stringent conditions were applied, with regulations stipulating that one engine should be used per

Table 1 Transition of F1 regulations

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Engine and powerplant	Supercharging	Prohibited from 1989																			
	Capacity	3500 cm^3 maximum					3000 cm^3 maximum											2400 cm^3 maximum			
	Number of cylinders	12 maximum										10						8			
	Homologation or limitation of specifications	Free																Limitations on fundamental dimensions, weight, and materials	Homologated		
	Mileage	Free														1 engine for 1 race event	1 engine for 2 race events		1 engine for 2 race events (Excluding FP1 & FP2)		8 engines for 1 season
	Rev limit	Free																	19000 rpm		18000 rpm
	Inlet systems	Free																Variable geometry prohibited			
	Cooling system water pressure	Free									3.75 bar maximum										
	Hybrid systems	Free									Prohibited										KERS permitted
	Refueling during race	Prohibited				Free															
Fuel	Properties	–		Specific gravity controlled	Type used by general public						Commercial fuel or fuel in development for future commercial use				Commercial fuel					Commercial fuel 5.75% (m/m) biofuel	
	Sampling	–					Sampling at circuit Approval before use														
Gear box	Automatic gear changing	Prohibited											Free			Prohibited					
	Forward gear ratios	Free				Minimum: 4; maximum: 7														7 maximum	
	Continuously variable transmission	Free											Prohibited								
	Clutch	Free												Twin clutch prohibited							
	Specification limitations	Free																		Limitations on fundamental dimensions and materials	
	Mileage	Free																		1 gear box for 4 race events (Excluding FP1 & FP2)	
Minimum weight of car	Machine weight	500 kg (without driver)	505 kg (without driver)				595 kg (with driver)	600 kg (with driver)				600 kg (with driver)				605 kg for qualifying (with driver) 600 kg for others (with driver)			605 kg (with driver)		
Chassis	EPS	Free												Prohibited							
	Ballast	–										Moving ballast prohibited and area of skid block fasteners limited									
Bodywork and dimensions	Overall width	2150 mm maximum			2000 mm maximum					1800 mm maximum											
	Facing ground	Flat bottom					Stepped bottom														
	Rear wing maximum height	1000 mm above ground			950 mm above ground		800 mm above reference plane														950 mm above reference plane
	Rear wing maximum width	1000 mm																			750 mm
	Rear maximum overhang	600 mm	500 mm													600 mm					
	Rear center diffuser maximum width	1000 mm					300 mm														1000 mm
	Rear diffuser maximum height	Free																		125 mm maximum (without center area)	175 mm maximum
	Front wing maximum overhang	1200 mm	1000 mm		900 mm																1000 mm
	Front wing maximum width	1500 mm	1400 mm																		1800 mm
	Front wing height	Up to height of front wheel rims (end plates)																			
		Free	At least 25 mm above reference plane			At least 40 mm above reference plane	Between 50 mm and 250 mm above reference plane						Between 100 mm and 300 mm above reference plane				Between 150 mm and 350 mm above reference plane				Between 75 mm and 275 mm above reference plane
	Enforcement of other bodywork limitation and deflection test						No body work area around front wheel	Height reductions just front of rear wheel			Side wing prohibited; Front wing test (downward); Rear wing assembly test (rearward)		Test just front of rear wheel (downward)		Splitter test (upward)	Rear wing top element test (rearward)	Rear wing front element test (downward)		Rear wing element bridge mandated		Designated front center wing
Tires	Tire width	18 inch maximum			15 inch maximum					Front 305-380 mm Rear 365-380 mm	Front 305-355 mm Rear 365-380 mm										
	Tire tread	Slick								Grooved Front-3 Rear-4	Grooved Front-4 Rear-4										Slick
	Tire supplier	–									Single supplier		–						Single supplier		
Electronically controlled devices	Traction control	Free					Prohibited		Software validation in advance				Free							Prohibited (Single ECU)	
	Launch control	Free					Prohibited		Software validation in advance				Free			Prohibited (FIA logger observation)					
	Chassis devices	Free				Prohibited															
Materials	Specific modulus	–										40 GPa/(g/cm^3) limit for engine moving parts	40 GPa/(g/cm^3) limit for all parts								
	Material designation	–																Designated for engine parts			
Safety	Frontal crash test speed	11 m/s					12 m/s				13 m/s	14 m/s							15 m/s		
	Side impact test	–					Mandated														
	Side panel penetration test	–										Specific designation	Mandated								
	Suspension tether	–									Single tether		Double tether								

two race events (from 2007, the Friday free practice (FP) session was excluded from the regulation). In 2009, the total number of engines that a team could use per year was limited to eight.

From 2006, in order to avoid cost increases resulting from excessive development competition, common basic dimensions for engines were established, and minimum weight and center of gravity of an engine were specified. Then, from the next year, 2007, a system of engine authorization (homologation), under which major engine specifications could not be modified once they had been registered, was introduced one year earlier than initially scheduled. At the same time, the use of variable geometry intake manifolds, previously allowed, was prohibited. The introduction of this homologation system represented a significant change in orientation for the Formula One philosophy, which as indicated above is based on free technical competition. Broad-ranging development efforts, seeking even minor enhancements of basic performance, were concentrated in the period immediately before the submission deadline for engine homologation applications, but following this, engine development was largely limited to subtle modifications within the allowable scope or tuning of characteristics.

In order to more thoroughly embody the way of thinking that sources of drive power other than engines should not be basically allowed, and to prohibit the hybrid systems that some teams were said to be using, in 1999, power sources other than 3000 cm^3 engines were prohibited, and the maximum recoverable stored energy was restricted to 300 kJ (the maximum stored energy recoverable at a rate greater than 2 kW was restricted to 20 kJ). From 2009, however, the use of a type of hybrid system called a Kinetic Energy Recovery System (KERS) has been allowed with the intention of promoting the development of environmental technologies through the medium of motor sports. These are the only systems excluded from the regulations discussed above. The maximum energy that can be input to or output from a KERS is 60 kW, and a maximum of 400 kJ can be recovered per lap.

Refueling during a race was prohibited for some time, but this prohibition was lifted from 1994, focusing attention on pit stop timing and the amount of refueling as aspects of race strategy. In line with this, technologies associated with aircraft refueling systems were applied, and from 1995 regulations stipulated the use of identical refueling systems able to safely and rapidly supply at a fixed refueling speed.

With regard to the composition of the fuel employed, while the interpretation that Formula One fuels should fundamentally be based on commercial fuels was upheld in the 11th round of the 1992 season[(2)], from 1999 to 2002, detailed rules concerning the ratio of various hydrocarbons in the fuel made it possible to use fuels that had been developed for the purpose of enhancing commercial fuels in the future. In addition, as a response to worldwide efforts to ameliorate global warming, from 2008, the regulations have stipulated the use of fuels containing a 5.75% ratio of biofuels.

3.2. Gearbox

A semi-automatic gearbox based on a sequential shift mechanism developed in the early 1990s, by means of which gears are shifted using a paddle attached to the steering wheel, has been continuously used as the standard Formula One gearbox type. As will be discussed below, from mid-2001, a significant relaxation in the regulations concerning electronically controlled systems temporarily enabled the use of automatic shifting systems that were not operated by the driver, but regulations were tightened to once again prohibit these systems in 2004 (as part of driver aids ban) over concerns that they would obscure differences in levels of skill between the drivers.

With regard to the number of forward gear ratio, there has basically been no change since the regulations stipulated a maximum of seven in 1994, but a prohibition on the use of continuously variable transmissions was added from the fifth round of the 2001 season. Following this, in 2002, regulations prohibited dual-clutch transmissions, which enable uninterrupted switching to the next pre-engaged gear stage. It was considered that a de facto prohibition existed on shift mechanisms that produced no discontinuity in torque, the ideal form of gearbox, but in 2005, BAR-Honda introduced a seamless shift using a one-way mechanism that the team had developed based on a close study of the regulations. Other teams sought to keep pace, and this has now become the standard technology in use in Formula One.

Since the 1980s, every team has employed original designs and methods of manufacturing gearbox case, which is a structural element of the chassis to which the suspension is mounted. In the first half of the 1990s, most gearbox cases were cast from magnesium, but after this a variety of methods came into use in attempts to produce lightweight, high-rigidity cases, including the manufacture of the cases from thin-walled titanium castings and welded plates, and the use of CFRP reinforcing. In 2004, BAR-Honda became the first team to produce a practically-applicable all-CFRP gearbox case.

With regard to the gears and shafts inside the gearbox, even in the early 2000s it was still standard practice, with some exceptions, to employ existing parts manufactured by gearbox makers. However, teams began to develop their own original gears as development competition seeking weight savings and greater compactness intensified. Based on concerns over spiraling costs, from 2008 the regulations have stipulated that forward gears should be manufactured from iron, and have also specified minimum gear width, gear weight, distance between shaft centers, and the like.

In 2008, the long-mileage concept was also applied to gearboxes, and a single gearbox is now required to be used for four race events. However, the adjustment of the gear ratios to match the characteristics of specific circuits and the replacement of the dog rings is allowed conditionally.

3.3. Chassis

In line with advances in electronic chassis control technologies in production vehicles, at the beginning of the 1990s the application of a variety of technologies was tested, including active suspension, traction control, four-wheel steering, and anti-lock brakes. Semi-active suspension had a particularly significant effect, enabling the realization of ride heights control that produced stable aerodynamic performance. However, based on considerations of performance control, and to control cost increases and ban driver aids, electronic chassis control systems were prohibited in 1994.

Power steering had been used in Formula One since the early 1990s, in order to respond to the increased steering force resulting from advances in aerodynamics and increased tire grip. From 1994, the use of this system was limited to the provision of assistance to the driver's physical effort. Initially, electronic power steering (EPS) systems were allowed if they satisfied this condition, and from the 12th round of the 2000 season through 2001, Honda led other teams in using a Formula One EPS system in racing[3]. However, because of the challenge represented by the verification of and judgment on the details of the control, making it possible that the systems incorporated control that functioned as a driver aid, the use of EPS was entirely prohibited from 2002, and hydraulic power steering systems are now used exclusively in Formula One.

The minimum weight of the vehicle was initially specified in regulations without the driver, and was 500 kg in 1990, increasing to 505 kg in 1993. From 1995 the driver was included in rules regarding minimum weight. In 1995 the figure was 595 kg, increasing to 600 kg in 1996. In 2004 the minimum weight was increased to 605 kg for the qualifying practice only, and in 2007 this was made the minimum weight for the entire race event. Compared to the previous circumstances, the minimum weight figures have not changed significantly in themselves.

In 1993, the maximum width of the vehicle, including the tires, was reduced from the previous 2150 mm to 2000 mm. The figure was further reduced to 1800 mm in 1998. In the case of formula cars, this directly means a reduction in track, and this regulation was applied in order to reduce the cornering limit speed of the vehicles by increasing load transfer on the left and right tires. While reducing the weight of their vehicles, teams began to make efforts to lower the center of gravity by even a small amount and thus increase the cornering limit speed, positioning corresponding ballasts, manufactured from a tungsten alloy with a high specific gravity, as low as possible in the vehicle. As a result of these efforts, the top teams came to employ ballasts weighing 70 kg or more. This enabled the front-rear weight distribution to be maintained towards the front of the vehicle while helping to ensure the dimensions of the front half of the vehicle (the distance between the front wheels and the side pontoons) necessary from an aerodynamic perspective, which was also effective in increasing warming of the tires and boosting the dynamic performance of the vehicle. In 2000, from considerations of safety, the regulations banned the use of movable ballasts and limited the area of the skid block fastener, which is used as the lowest ballast on the vehicle.

In an attempt to significantly lower downforce, which had previously been continuously increasing, and thus to reduce the cornering limit speed, in 1995, flat bottom rule was replaced by a stepped bottom rule that would increase the distance between the bodywork facing the ground and the road surface, and the use of skid plates that would increase the ground clearance was also stipulated. However, a high nose configuration that increased downforce by encouraging air flow beneath the vehicle had been developed in 1990, and this configuration was applied by all teams in 1996. Efforts were also made to increase the contribution of the shape of the front suspension to vehicle aerodynamics. A twin keel mount was introduced in 2002 and a zero keel configuration was introduced in 2005. Nevertheless, since the front suspension stroke is extremely small in Formula One vehicles, the tendency has been to emphasize rigidity over geometry.

In parallel with this, from about 1991, the regulations concerning the dimensions of the front and rear wings and the diffusers positioned in the rear of the bodywork facing the ground, which were making an increased contribution to aerodynamic performance, began to be reviewed. Since 2000, the regulations have been made more stringent on an almost annual basis. In addition, given various advancements in aerodynamic components such as vortex generators, bargeboards, and winglets, designed to increase the overall downforce of the vehicle by adjusting the flow of air around different parts of the body, a large number of additions have been made to regulations concerning the dimensions of parts of the vehicle body.

In addition, as a result of the use of flexible wings to reduce aerodynamic drag at high speed, since 1999 regulations have stipulated measurement of the level of deformation of each part of the vehicle body and the fitting of stiffening elements, among other requirements.

The previously used slick tires, which had no grooves, were replaced by grooved tires from 1998, in order to reduce the absolute level of grip. In 1999, one extra groove was added at the front of the tires for a total of four front grooves and four rear grooves. This configuration was employed until 2008. The stiffness of the tread rubber of grooved tires is low; they are prone to delay in response and present issues of controllability. In addition, they are also challenging to handle, with the blocks between the grooves being deformed to incline and abrasion termed graining tending to occur commencing from the edge. Appropriate temperature management of the tires is necessary for the effective use of these grooved tires. At the same time, it is also necessary to increase controllability, maintaining the overall vehicle balance and a minute transient response characteristic. In 2009, there was an extensive review of aerodynamic issues, and aerodynamic regulations were introduced based on the concept of lowering cornering performance and reducing the effect of the wake of the vehicle in front, in order to enable active overtaking. At the same time, high-controllability slick tires were reintroduced.

3.4. Control

It is the fate of control systems in Formula One to be constantly subject to regulations from the perspective of driver aids ban. It is more challenging to regulate engine-based torque control systems such as traction control than chassis-based control systems, in the case of which it is comparatively simple to make a judgment based on whether a device is fitted or not. Since 1997, a software validation in advance has been mandatory, but even if the FIA inspections were to confine themselves to a hotel room with the team members for several days for each team in order to check source code, it would still not be possible to achieve complete restriction. Perhaps because regulations relating to this area had reached their limit of operability, from the 5th round of the 2001 season, regulations were abolished for all forms of software excluding safety-related software, and engine torque control became effectively free.

This did not only affect traction control. Development has also proceeded in other areas, including engine brake control and over-run control, which achieves a type of ABS effect by using engine torque during braking to help keep the rear wheel brakes from locking.

Launch control, which increases acceleration by making maximal use of the tire grip at race start, which changes moment by moment, also advanced considerably. However, from 2004, launch control was prohibited through detailed regulation of the method of using the engine and the clutch, and the introduction of a method of using standardized FIA data loggers which should be fitted to vehicle to monitor the way of using them.

Following this, from 2008, torque control, including traction control, was once again prohibited because the requirement to fit a standardized FIA ECU to vehicles made it possible for the first time to accurately manage the regulation.

3.5. Materials

There had previously been few rules in the regulations concerning materials of formula one vehicles, but attention was directed to them when the use of beryllium alloys, which are harmful to human health, became an issue, ultimately leading to restrictions on the use of expensive lightweight and high-rigidity materials. In 2000, materials with a specific modulus of elasticity of greater than 40 GPa (g/cm^3) were prohibited from use in any part other than the moving parts of the engine, and in 2001 this prohibition was extended to the entire vehicle. In 2003, methods of testing compliance were detailed.

While materials development programs had previously been focused exclusively on the achievement of low weight and high rigidity, in response to these changes, fine control began to be applied to the composition and process of production of materials, and more advanced technologies were pursued, for example by developing surface treatments and conducting research at the molecular level, in order to realize desirable materials that are able to achieve high performance levels while remaining compliant with regulation rules concerning composition and physical values.

Since 2006, detailed regulations have been in effect concerning the types of materials that can be used for each engine part, and development has continued within the scope defined by the regulations.

3.6. Safety

The deaths of Roland Ratzenberger and Ayrton Senna in accidents in 1994 resulted in a large-scale revision of the regulations seeking a rapid enhancement in passive safety. Continuous changes to the regulations have also been made since then, and as a result no Formula One driver has been killed in an accident in the intervening 15-year period. More details can be found in two previously published papers[(1),(4)].

In the opening round of the 2001 season, the BAR-Honda vehicle being driven by Jacques Villeneuve ran head-on into another vehicle and became airborne before suffering a severe crash. Protected by a robust carbon monocoque, Villeneuve escaped with almost no injuries. Tragically, however, a wheel torn off the vehicle struck and killed a track official. Since 1999, regulations had already stipulated the use of suspension tethers between the uprights and the chassis in order to help reduce this type of accident, and standards have been raised each year. However, given the fact that the achievement of complete safety is not a realizable goal, the regulations have continued to be enhanced since the following year.

4. Trends in Formula One Regulations and Their Effects

Formula One regulations are formulated based on considerations of fairness, competitiveness, safety, sustainability, and entertainment value[(1)]. If the changes in the regulations discussed above are summed up as a whole, certain trends can be observed from the 1990s to 2009, and these trends have also had a significant impact on the direction of technical development. These trends will be discussed below.

In 1994, the first driver death in eight years made the 1990s a period in which reconsideration of Formula One safety was pushed ahead rapidly. From 2000, when Honda reentered Formula One racing, until today, the application of limitations to vehicle performance and the achievement of increased vehicle safety have been constantly promoted. The limitation of vehicle performance has mainly focused on restriction of driving performance, primarily by means of engine regulations, and the application of regulations concerning chassis dimensions, aerodynamics, and tires, focusing on the reduction of cornering speed.

In order to seek enhanced performance and help to ensure competitiveness against the background of these regulations, teams have pushed ahead with the development of new high-efficiency mechanisms that reduce loss and modifications based on heat and flow analyses conducted using computers. Developments focusing on the achievement of weight savings, increased compactness, and higher rigidity – universal and important elements of development for racing – have not rested with simple substitution of materials, but have entered a new stage, with limit design using structural analysis technologies and the development of sophisticated technologies to engineer characteristics and functions into materials, among other initiatives.

In addition, a change in technical orientation that seeks to increase competitiveness by enhancing not only the performance of each technical element but also the overall balance of the vehicle as a package, which could already be observed in the 1990s, became particularly important in the 2000s. The reduction of the maximum width of the vehicles discussed above reduced the clearance between the tires and the bodywork, and the efforts to realize a low, slim rear cowl with consideration of the flow to the rear wings was related to the reduction in the size of the engine, the use of a narrow longitudinal shaft gearbox, and, further, the length and arrangement of the exhaust pipes.

A variety of measurement, analysis, and simulation technologies have come to be employed to help ensure the competitiveness of the vehicles, but for the evaluation of the results of developments, it has become necessary to once again consider what is after all the fundamental predicate of Formula One, i.e., having actual drivers run the vehicles at high speeds. The rapid advancement of computer technologies has enabled Formula One developers in the 2000s to process large volumes of data at high speeds, and to push ahead with sophisticated technical developments spanning a broad range; at the same time, Formula One in this era is a world in which systems of comprehensive technical management that bring these technologies together and technical philosophy themselves are under scrutiny.

Figure 1 shows how lap times in Formula One qualifying practice sessions have changed since 2000 as a result of these changes in the regulations and subsequent technical developments. For the base data, a track was selected on which there had been no change in the length of a lap in nine years; results for rainy weather were excluded. The figure shows the transition in the rate of reduction in the fastest qualifying lap times with the time for 2000 as the benchmark. As the results make clear, despite ongoing changes in the rules aimed at restricting vehicle performance, such as the 20% reduction in engine displacement introduced in 2006, there has been almost no increase in lap times. Times have either been reduced, or have at least been held steady.

This indicates that Formula One is technically incomplete, and there is still margin for enhancement. In particular, the importance of the effect of tires on performance in contemporary Formula One is demonstrated by the rapid reduction of lap times in the period when multiple tire suppliers were in competition, and the deterioration in lap times in 2005, when tire changes were prohibited from the qualifying practice to the completion of the final race.

It has long been feared that the fierce competition in development for Formula One will lead to spiraling costs, and specific regulations have been rapidly put in place to reduce costs against the background of the recent deterioration in global economic conditions. These

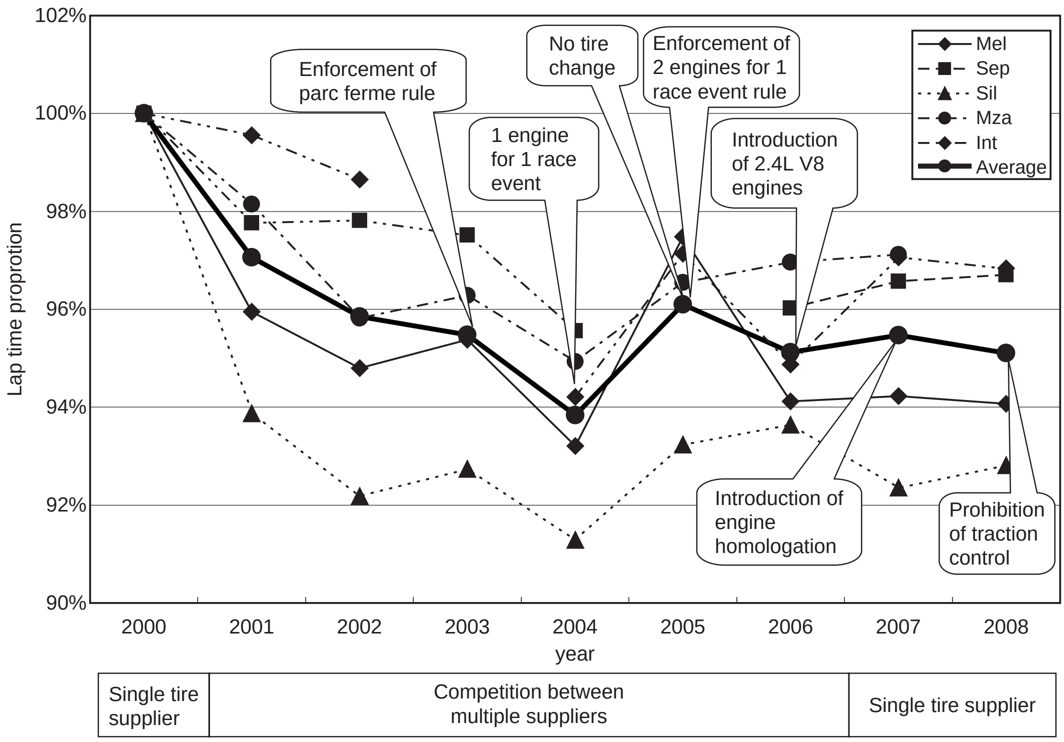

Fig. 1 Transitioin of lap time

regulations do not restrict themselves to regulations concerning the materials that can be employed and the like; a variety of new regulations have been added, including regulations extending the life of engines and gearboxes, regulations concerning a homologation system that will limit development itself, regulations restricting the distance and the amount of days for running tests, and a parc ferme rule designed to reduce the amount of operations at the circuit by prohibiting repair or adjustment of vehicles from the qualifying practice until the completion of the final race. However, if for example running tests are restricted, developers will turn to bench tests and simulations, and the development of these methods themselves will increase in importance. In response, the FIA is seriously considering the introduction of measures, including restrictions on the amount of time that development facilities can be used and a cost cap system that will control total development costs.

Environmental measures are also being emphasized in response to global warming, and the recent recommendation of technologies enabling energy to be reused and the introduction of obligation to control total CO_2 emissions from fuels are noteworthy points.

Efforts are also once again being made to highlight the competition that is fundamental to racing, and to increase the excitement and spectacle of Formula One. The ability to make the spectators feel the differences in skills and the individuality of the drivers, and to transmit the thrill of a race fought out at white heat will be a necessary element in helping to ensure the sustainability of Formula One into the future.

As indicated by the discussion above, we can point to present day as an era in which Formula One is reflecting upon the very meaning of its existence as it responds to rapid social changes. A vehicle that is responsive to any driver input will run fast, and eventually be safe, non-fatiguing, and enjoyable to drive. While the environments in which and the speed at which they are operated are very different, Formula One vehicles and production vehicles share this fundamental characteristic. The author can only express his hope that technical development for Formula One will continue to contribute to fundamental advances in vehicles.

5. Conclusion

Formula One encompasses a variety of aspects, including competition, technical rivalry, and entertainment, and the like. Having failed to achieve a good record of victories, it would be difficult to say that Honda's activities during its third Formula One era achieved their purpose in increasing recognition of the company or enhancing its image. However, we applied ourselves with a respect for sportsmanship, a dedication to technical development, and an indomitable spirit. The various technical outcomes and primary experiences that were obtained are valuable assets to the Honda, and the process itself can be said to be emblematic of the Honda approach.

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■ Author ■

Hiromasa TANAKA