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F1 2014: Turbocharged and Downsized Ice and Kers Boost

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Abstract. The paper discusses the FIA's World Motor Sport Council (WMSC) new regulations for F1 power trains. The new regulations will see the 2.4 liter V8s currently used replaced by 1.6 liter V6s engines starting in 2014. The power units will have high pressure gasoline direct injection up to 500 bar. Engine speed limits on the new engines will be reduced from the current 18,000 rpm to a maximum of 15,000 rpm. The more environmentally-friendly units will be supported by augmented power output of the engine via energy-management and energy-recovery systems. The paper discusses the possible performances the novel F1 cars could achieve with these novel engines and kinetic energy recovery systems, as well as the declared goal of making the F1 racing greener, the relevance of F1 to road cars, and finally the use of resource restrictions in F1. The major issue with new F1 rules is not just the total cost of research and development within the budget, but the ability to make the most out of the investment made for a more sustainable and greener road transport. The proposed high torque 475 kW 1.6 liter V6 turbo engine coupled with the proposed small 0.3 MJ 120 kW mechanical KERS may permit fuel savings of 40% vs. today's low torque 525 kW 2.4 liters V8 naturally aspirated and even better driving performances on the most part of the race tracks.

Keywords: racing engines, turbocharging, kinetic energy recovery systems, downsizing

1 Introduction

The FIA's World Motor Sport Council (WMSC) approved new regulations further adding to the struggle between traditional notions of auto racing and new environmental and cultural challenges. The new regulations will see the 2.4 litre V8s currently used by Formula One teams replaced by 1.6 litre V6s engines starting in 2014. The power units will have high pressure gasoline injection up to 500 bar. Engine speed limits on the new engines will be reduced from the current 18,000 rpm to a maximum of 15,000 rpm. The more environmentally-friendly units will be supported by augmented power output of the engine via energy-management and energy-recovery systems. More than 35% reduction in fuel consumption is expected whilst providing same level of performance enjoyed by today's F1 drivers. Additional revisions to the regulations will see a drop in the number of engines at drivers' disposal currently set to eight units a season without penalty. Checks and balances will continue to apply to ensure that costs are contained and that performance across all engines remains comparable, with resource restriction such as limiting the number of people or allocated time that can be devoted to a project which is considered the most effective measure to contain costs.

Many people involved in the F1 of the past (and the authors of this paper) believe that F1 is not any more a sport in the traditional sense but a huge business. This is demonstrated not only by the increasing number of circuits in all the parts of the world, but also with races in all the hours of the day and the night to make the show. The main players of the racing world take advantage of the old tale that F1 is the tip of diamond of the automotive technique, and with such statement they ride the present time with topics such as the ecology and the energy saving, even if all the proposed solutions have no real link with the automotive world. In 2011, in order to keep F1 in line with energy savings it was necessary to adopt abstruse devices (such as strategically

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movable wings and strategically discharged kinetic energy recovery systems) used according to abstruse rules. In this paper we will try to figure out where F1 will be heading following the new rules just proposed, and possibly which changes should be adopted to restore at least partially the attractiveness F1 racing engines used to have when the regulations allowed more freedom.

An engine is the only power source of a Formula One car apart from the kinetic energy recovery system in 2009 which was supplementing the internal combustion engine output with the braking energy recovered. Because of the regulations and the very limited engineering optimizations permitted, all the current F1 engines (2011 season) are similar. All the engines are naturally aspirated V8's of 2.4 litre limited to 18,000 rpm. The minimum weight is exactly 95 kg, a value each manufacturer easily reaches. Engine blocks are constructed of forged aluminium alloy. Usage of non-ferrous materials is not permitted. Crankshaft and piston rods are also Iron based.

All the engines are very similar due to the very stringent regulations that have increasingly come into play since 2006 to cut the spending, to make performance gains and drastic weight cuts at the same time. By the end of 2005, most of the teams converted their designs to 3 litres V10's with an internal angle of 90 °. The teams' designers came to the conclusion that 90 ° was the best compromise between performance and stiffness of the engine itself. That same year, some 3 litre V10 engines were running very close to the 746 kW / 1,000 HP marks, a figure that was never reached since the ban on turbo engines. The maximum capacity was thus reduced to 2.4 litres and the cylinder number to 8. Additionally, the FIA ruled that freezing the engine size would come into effect a year later to put an end to the spiralling spending for each race event.

Only after 2 years however, halfway through 2008, the FIA found that the regulations were still allowing too much freedom. Several meetings with FIA officials and the teams' principals then resulted in an equalization of the engines, in which the less powerful could put on several updates to be on par in the following years. It is estimated that a new F1 engine can produce around 535 kW / 720 HP running at 18,000 rpm.

V-type engines are currently used in all F1 cars. The V is in fact the geometrical angle that separates the two cylinder banks from each other where the crankshaft can be considered the origin of the angle. Obviously for this type of engine the size of the V is a major factor and must be decided in the first phases of the engine design. Previously, engines have been designed with angles such as 60 ° V12 or 72 ° V10. Although it has historically been an interesting evolution to see the differences between the teams' engines, the FIA have fixed the engine type to 90 ° V8 models. An engine in a F1 car today is a stressed member of the chassis, meaning that it is an integral part of the car. V-type engines have gradually pushed out any other engine type because they are compact and can be constructed very rigidly without requiring further strengthening to the chassis to ensure stiffness.

The current regulations on Formula One engines can be briefly summarized as follows. F1 specifications have become more stringent during recent years in an attempt to limit costs and decreased performance. Only 4-stroke engines with reciprocating pistons are permitted. Engine capacity must not exceed 2.4 litres. Crankshaft rotational speed must not exceed 18,000 rpm. Supercharging is not permitted. All engines must have 8 cylinders arranged in a V90 configuration and the normal section of each cylinder must be circular. Engines must have 2 intake and 2 exhaust valves per cylinder. Only reciprocating poppet valves are permitted. The sealing interface between the moving valve component and the stationary engine component must be circular. Cylinder bore diameter may not exceed 98 mm. Cylinder spacing must be fixed at 106.5 mm$(+/-0.2\text{ mm})$.

The crankshaft centre line must not be less than 58 mm above the reference plane. The overall weight of the engine must be a minimum of 95 kg. The centre of gravity of the engine may not lie less than 165 mm above the reference plane. The longitudinal and lateral position of the centre of gravity of the engine must fall within a region that is the geometric centre of the engine $(+/-50\text{ mm})$. The geometric centre of the engine in a lateral sense will be considered to lay on the centre of the crankshaft and at the midpoint between the centres of the forward and rear most cylinders bores longitudinally. Variable geometry systems are not permitted. Magnesium based alloys, Metal Matrix Composites (MMC's) and inter-metallic materials may not be used anywhere in an engine. Coatings are allowed provided that the total coating thickness does not exceed 25% of the section thickness of the underlying base material in all axes. In all cases the relevant coating must not exceed 0.8 mm. Pistons must be manufactured from an aluminium alloy which is either Al-Si; Al-Cu; Al-Mg or Al-Zn based.

Piston pins, crankshafts and camshafts must be manufactured from an iron based alloy and must be machined from a single piece of material. A supplementary device temporarily connected to the car may be used to start the engine both on the grid and in the pits. The use of Kinetic Energy Recovery Systems (KERS) is not compulsory. Several teams used KERS during the 2009 season. An agreement between constructors precluded the use of KERS in 2010. KERS are back in 2011. In 2009, KERS of power limited to 60 kW were forced to dispense less than 400 KJ of energy a lap. 2011 KERS are pretty much the same of 2009. Current power and energy caps are due to increase in the following years thus permitting better chances for this technology that however is a strategic gadget rather than a fuel saving device. Only a very limited amount of the recoverable braking energy is stored in the KERS to help the driver to gain a position or maintain a position with a boost very limited in time. Less fuel energy efficient battery and electric motor based KERS are preferred to more fuel efficient flywheel

FIA decided to switch from the current 2.4-liter V8s to 1.6-liter turbo engines with energy recovery systems and fuel restrictions in a move to make racing greener mirroring the trend towards fuel-efficiency in road cars. The aim was to force F1 to embrace sustainability and be more road-relevant in the future improving the efficiency of F1 engines by as much as 50%. Care was taken to ensure the performance of cars will not be affected and total power outputs will remain at current levels of approximately 545 kW. In the first version of the new rules, framed to start in 2013, these 1.6-liter engines would be four-cylinder and the revolution limit is set to 12,000 rpm. Certain parties involved did not think that an I-4 engines was appropriate (or the best choice), and so the FIA decided that these engines to be V6 with a revolution limit set to 15,000 rpm and introduction delayed to 2014.

Checks and balances are enforced to ensure costs are contained and performance across all engines remains comparable (and this is the real threat to both the competition and the relevance to road cars as discussed later). The checks and balances written into the recent F1 regulations ensure it is impossible for one manufacturer to get an upper hand on the others in terms of performance more than keeping down the research and development costs in particular or the F1 total costs in general. This is primarily done through resource restriction such as limiting the number of people or time that can be devoted to a project. Turbochargers are basic single stage turbine and compressor.

Plan for advanced turbochargers are to be introduced in subsequent years. About 425 kW/600 HP of the 545 kW/750 HP produced by the engines will come from the single-turbo engine itself, with the rest being provided by energy storage and power-boost systems. Power of KERS is set to increase from 60 kW in 2011 to 120 kW in 2014. Fuel consumption will be restricted both by limiting fuel flow and introducing a maximum capacity for races. Fuel mass flow rate must not exceed 100 kg/h and below 10,500 rpm, the fuel mass flow rate must not exceed Q (kg/h) $= 0.009 * N$ (rpm) $+ 5$. For over 80% of the maximum permitted fuel flow rate, at least 75% of the fuel flow must be injected directly into the cylinders. There may only be one direct injector per cylinder and no injectors are permitted downstream of the exhaust valves. Further details of the latest rules 2014 F1 Technical Regulations 23/77 14 July 2011 are provided in [1].

2 Downsizing and turbocharging

The BMEP and BSFC data of current (or very near) production gasoline engines [2] shows peak BMEP now approaching 25 bar and minimum BSFC about 240 g/kWh in mass production engines with revolutions limited to up to 6,000 rpm. These values are not the target values of near future gasoline engines, that with a more aggressive research and development may certainly produce much better BMEP and BSFC values, just a picture of current (or very near) production gasoline engines.

Fig. 1 presents the BMEP of some naturally aspirated racing engines of the mid-nineties (from [7]). The classic naturally aspirated engine design with port fuel injection and tuning of the intake and the exhaust for power and torque permits to define a limiting curve these naturally aspirated racing engines that could have limits at different speeds as dictated by different engine rules for different applications. Fig. 1 presents data from past F3, touring and F1 engines (latest rules in [4–6] differing from the ones of the time). It is remarkable

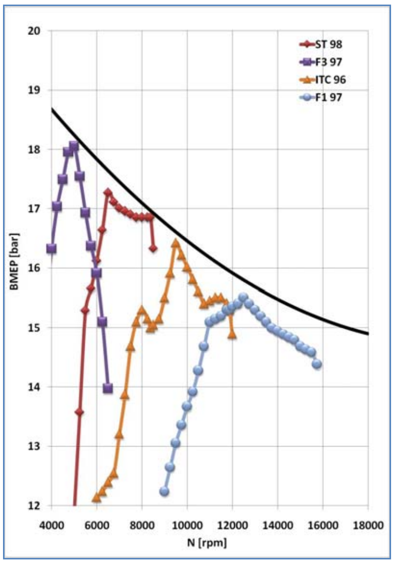

Fig. 1. BMEP of naturally aspirated racing engines of the mid-nineties

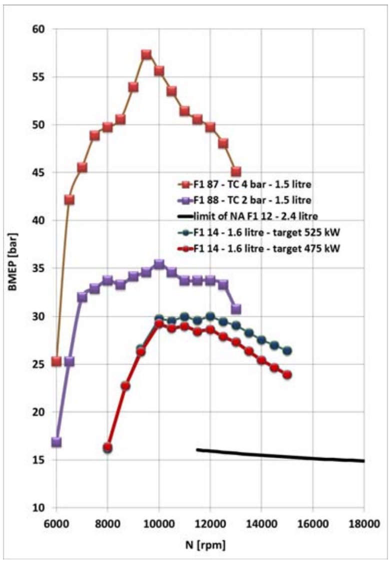

Fig. 2. BMEP of turbocharged racing engines of the mid-eighties and of the novel F1

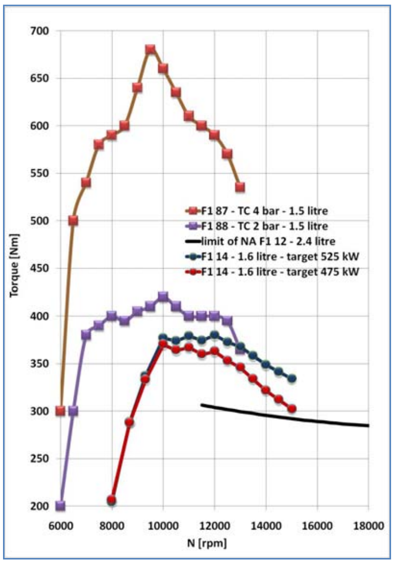

Fig. 3. Torque of turbocharged racing engines of the mid-eighties, of today's F1 engines and of the novel F1 engines

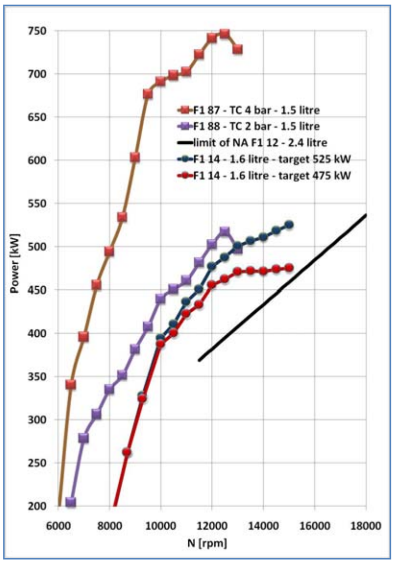

Fig. 4. Power of turbocharged racing engines of the mid-eighties, of today's F1 engines and of the novel F1 engines

that the fact that similar design concepts produce pretty much the same limiting curve no matter how much additional money is spent to further refine the engine design, particularly those for the F1 97 vs. the ST 98 engines which are an order of magnitude apart. Further details about the design philosophy of the naturally aspirated racing engines of the nineties may be found in [7].

Fig. 2 presents the BMEP of some turbocharged racing engines of the mid-eighties, namely those of the 1987 and 1988 seasons, basically differing in the fuel limit and the boost pressure (from [16]). The technologies developed 30 years ago were permitting more than 55 bar BMEP in these F1 engines running up to 12,500 – 13,000 rpm vs. the 15-16 bar BMEP estimated for today's F1 engines limited to 18,000 rpm. The picture also shows the BMEP profile targeted in the novel 1.6 litre F1 engines revving 15,000 rpm with maximum power outputs of 475 and 525 kW. This window for the power output is due to the fuel flow rate capped to 100 kg/h above 10,500 rpm, and to Q (kg/h) = 0.009 N (rpm) + 5 below 10,500 rpm making unrealistically higher outputs. A BMEP estimation of today's V8 2.4 litre naturally aspirated engines using the limiting curve of Fig. 2 is also provided.

Fig. 3 presents the torque of some turbocharged racing engines of the mid-eighties and today's F1 engines. 30-year old technologies were permitting 750 Nm of torque with 1.5 litre engines vs. the about 300 Nm of torque of today's F1 engines. The picture also shows the torque profile targeted in the novel 1.6 litre F1 engines revving 15,000 rpm with maximum power outputs of 475 and 525 kW. A torque estimation of today's V8 2.4 litre naturally aspirated engines using the limiting curve of figure 1 is also provided. The novel small, turbocharged engines are expected to deliver similar torque outputs of the larger, naturally aspirated engines due to the fuel constraints.

Fig. 4 presents the power of some turbocharged racing engines of the mid-eighties and today's F1 engines. 30 years old technologies were permitting 746 kW – 1,000 HP of power with 1.5 litre engines revving at 12,000 rpm vs. the about 545 kW – 730 HP of today's F1 engines. The picture also shows the power profile targeted in 1.6 litre F1 engines revving 15,000 rpm with maximum power outputs of 475 and 525 kW. A power estimation of today's V8 2.4 litre naturally aspirated engines using the limiting curve of figure 1 is also provided.

The novel small, turbocharged engines are expected to deliver significantly smaller power outputs than the larger, naturally aspirated engines due to the fuel constraints.

To reach a power of 525 kW revving at 15,000 rpm, the novel 1.6 litre V6s turbocharged engines would have to produce about 26.4 bar BMEP at top speed. This is definitively nothing special requiring particular research and development to be achieved. However, actual targets are even much less than that, because the targeted power curve of today's V8 2.4 litre naturally aspirated engines is supposed to be obtained with some support from the 120 kW KERS reducing the thermal engine contribution. The 475 kW revving at 15,000 rpm translate in about 23.9 bar BMEP at top speed that is not exactly what is expected from a high tech turbocharged racing engine.

It is worth of mentioning that the F1 KERS is a strategic power boosting device and absolutely not the fuel saving device of road cars, where up to almost 70% of the braking energy is used to accelerate the car following the deceleration over driving cycles, and the energy recovered is actually used as a power boost in the acceleration immediately following a deceleration with the subsequent benefits in terms of both fuel economy and effective power and torque curve larger than the curves of the thermal engine.

F1 KERS have rules setting the difference between the maximum and minimum state of charge of the Energy Storage (ES) that may not exceed 4MJ at any time the car is on the track, the energy input from the Motor Generator Unit - Kinetic (MGUK) to the Energy Store (ES) that may not exceed 2MJ in any one lap, and the energy released from the ES to the MGUK may not exceed 4MJ in any one lap.

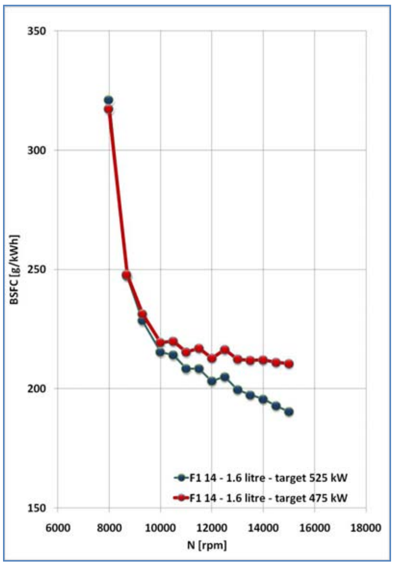

Fig. 5. BSFC targeted in novel 1.6 liter F1 engines

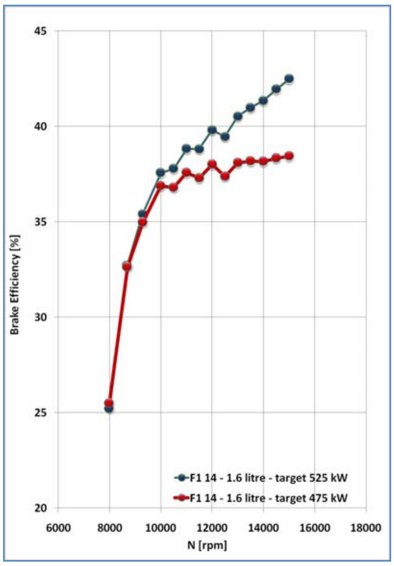

Fig. 6. Brake efficiency targeted in novel 1.6 liter F1 engines

This is certainly better than the 2009 and 2011 rules, but still not enough to make of the KERS the device needed to support same of today performances and much better than today fuel economies over a race. During sharp decelerations, braking is still mostly friction braking and not KERS braking. The KERS are usually fully charged, because the driver uses the KERS boost when strategically convenient to gain or defend positions. During a deceleration, therefore only a very small percentage of the braking energy is stored as KERS reusable energy.

Fig. 5 presents the BSFC targeted in 1.6 litre F1 engines revving 15,000 rpm with maximum power outputs of 475 and 525 kW, while Figure 6 presents the brake efficiency. Considering a conservative Lower Heating Value (LHV) of 44.5 MJ/Kg, a fuel energy supply capped to 1236 kW would translate in a fuel conversion efficiency of 38% and a brake specific fuel consumption of 210 g/kWh at top power and speed for the novel engine targeting the 475 kW output. (At minimum fuel consumption, BSFC of turbocharged F1 engines PFI from 30 years ago were around 270 g/kWh with powers about 460 kW at speeds around 12,000 rpm). The 525 kW output would be certainly an evolutionary break-through for spark ignition engines, being this value compatible only with quite unlikely efficiencies approaching 42.5%.

We do not expect F1 engines will reach these efficiencies above 40%. Therefore, very likely the new F1 engines will not be that advanced vs. the past F1 experiences as well as the current production of turbo GDI engines for road applications, with the power output decreasing considerably vs. the current V8 2.4 litre naturally aspirated engines.

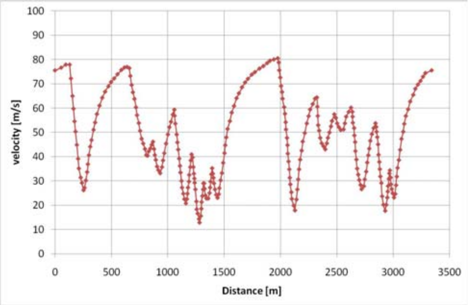

Fig. 7. Velocity vs. distance of a F1 car covering one lap at Monte Carlo (from [3])

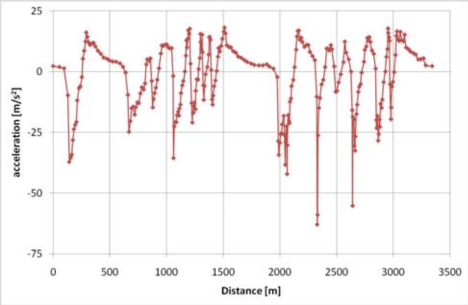

Fig. 8. Acceleration vs. distance of a F1 car covering one lap at Monte Carlo

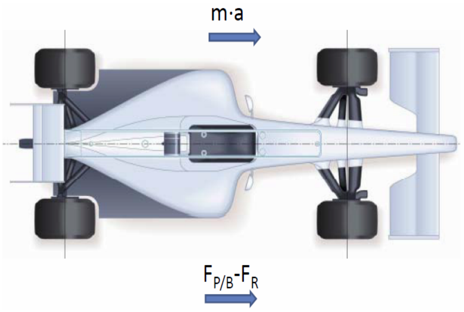

Fig. 9. Free body diagram for vehicle dynamics

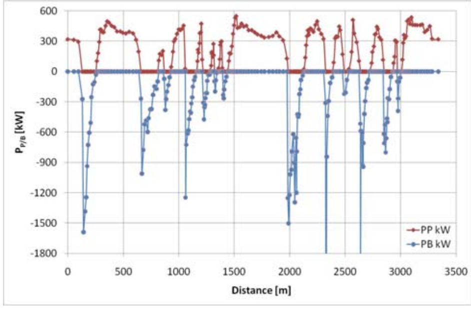

Fig. 10. Propulsive (positive) and braking (negative) power vs. distance of a F1 car covering one lap at Monte Carlo

3 Vehicle dynamic and braking energy recovery

Fig. 7 presents the velocity of a F1 car vs. the distance covering one lap of the Monaco GP (data taken from [3]). The KERS is not used during this lap. From this curve, we may then estimate the engine and the braking powers as well as the engine and the braking energy. If s is the space and v the velocity, then the acceleration is $a = v \cdot \mathrm{d}v/\mathrm{d}s$. This acceleration is presented in Fig. 8. Then, if FP/B is the propulsion or the braking force and FR is the retarding force due to the aerodynamic drag, the rolling resistance and all the frictions, $(FP/B - FR) = m \cdot v \cdot \mathrm{d}v/\mathrm{d}s$, where m is the mass of the car. The weight of the car is taken equal to 660 kg. For what concerns the aerodynamic drag, we approximate the retarding force with the aerodynamic drag force $1/2 \cdot \rho \cdot v2 \cdot CD \cdot A$, where ρ is the air density, CD is the drag coefficient and A is the frontal car area. We take $\rho = 1.29\ \mathrm{kg/m^3}$, $CD = 0.5$ when $A = 1.5\ \mathrm{m^2}$ for the specific very low speed circuit. Finally, the propulsive or braking power is simply estimated as $PP/B = FP/Bv$. Fig. 9 presents the free body diagram for the simple vehicle dynamic considered. Fig. 10 presents these propulsive (positive) and braking (negative) power vs. distance. Some spikes in the acceleration and power curves are the result of the accuracy in evaluating the velocity in different space locations along the race track.

Fig. 10 is quite important, because it enables us to give a first estimation of the propulsive energy requested to the engine and the braking energy requested to the brakes. Considering $v = \mathrm{d}s/\mathrm{d}t$, this gives us a lap time of 1.15.82 within the range of the practice times of 2011. This first estimation of the propulsive power the engine has to supply to accelerate the car and of the braking power needed to decelerate the car tell us the engine power approaches 550 kW, while the braking power may reach values below 1500 kW.

Fig. 11 tells us that the propulsive energy the engine has to supply to cover a lap in Monte Carlo is 13.807 MJ, while the braking energy is a very substantial -8.902 MJ. Apart from the difficulty to brake the car with KERS at a deceleration exceeding 6 g as with today's friction brakes, the picture shows the huge potentials of the KERS. If properly developed, KERS may certainly permit to achieve dramatic fuel energy savings using part of the braking power to reaccelerate the car after a sharp deceleration.

Unfortunately, the braking energy recovery is not only limited by the power and the energy storage of the KERS, but also by the balance in between the front and rear axle braking and the balance in between rear wheels KERS and friction braking of the traditional rear wheel drive F1 car with a driveline KERS and definitively an energy recovering braking event will be less efficient than a purely friction braking event in terms of braking times and distances[15].

Energy storage at powers much higher than 120 kW does not make too much sense for an F1 car. Firstly the aero drag is so huge that there is much less energy available at very high vehicle speeds and secondly the very high energy numbers only last for a fraction of one second.

The amount of energy available but unrecovered by a 200 kW system would be already very small and it is not worth carrying the weight of the more powerful system for the very small amount of extra energy that would be recovered. Furthermore, very high power storage creates large losses so it means a large cooling requirement, with the aerodynamic drag of the cooler will slow the car down by more than the extra few kW for a few seconds.

If the energy input from the Motor Generator Unit - Kinetic (MGUK) to the Energy Store (ES) may not exceed 2MJ in any one lap and energy released from the ES to the MGUK may not exceed 4 MJ in any one lap, this means that the continuous use of the KERS is limited to just the 2 MJ recovered and reused per lap, while in the strategic use of the KERS the 4MJ could be made available in a lap providing in the previous lap there has been no discharge of the KERS.

The 2MJ maximum charging per lap means that on average the braking energy lost will be 80% of the theoretically available, and this is certainly not a huge target, considering applications to road cars have shown potentials to recover 70% of the braking energy even if braking much less sharply than in F1.

We may conclude from these data that while the strategic KERS 60 kW capped to 0.4 MJ of the current season does not help too much to save energy and improve constantly the performances, while the 120 kW KERS capped to 2 MJ may help a little bit more to improve both the performances and the fuel economy.

Fig. 12 presents the regenerative braking energy of a F1 car covering one lap in Monte Carlo with a 120 kW mechanical KERS[8–14] used for energy saving and uncapped energy flow to the KERS. During braking, the KERS is charged at a maximum rate of 120 kW or the braking power if less in module with a charging efficiency assumed equal to 84%. During acceleration, the KERS is discharged at a maximum rate of 120 kW or the propulsive power if less with a discharging efficiency also assumed equal to 84%.

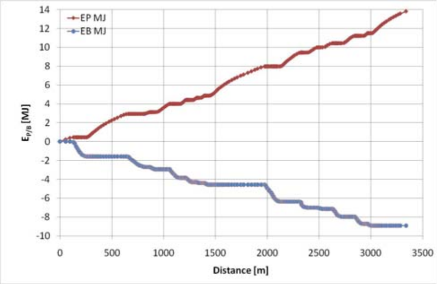

Fig. 11. Propulsive (positive) and braking (negative) energy vs. distance of a F1 car covering one lap at Monte Carlo

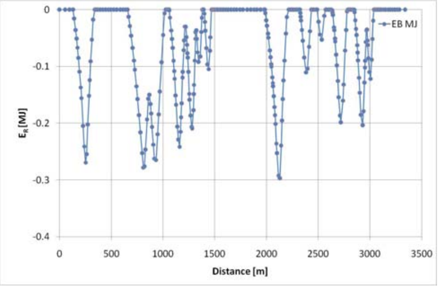

Fig. 12. Mechanical KERS regenerative energy vs. distance of a F1 car covering one lap at Monte Carlo. The braking and propulsive powers are supposed to be unchanged with and without the KERS for same lap time

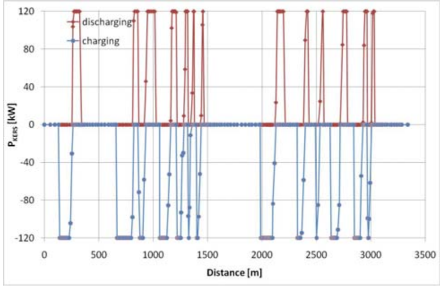

Fig. 13. Power to and from the mechanical KERS vs. distance of a F1 car covering one lap at Monte Carlo. The braking and propulsive powers are supposed to be unchanged with and without the KERS for same lap time

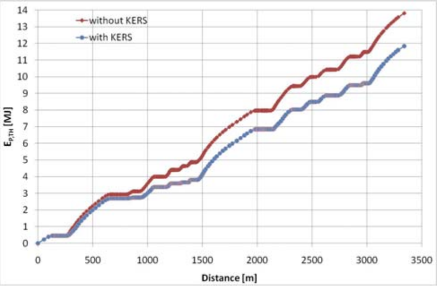

Fig. 14. Thermal energy with and without the mechanical KERS vs. distance of a F1 car covering one lap at Monte Carlo. The braking and propulsive powers are supposed to be unchanged with and without the KERS for same lap time

The total round trip efficiency of the mechanical KERS is therefore taken equal to a flat (0.85)2=0.7225 %.

This charging and discharging is not controlled by the driver, and a very sophisticated control of the balance of friction and regenerative braking over the four wheels will be certainly needed to get closer to these figures in an actual car. The maximum amount of energy stored in the flywheel at any time is less than 0.3 MJ. This permits a much simpler design than a KERS supposed to store up to 4 MJ of energy for strategic usage. The total energy flow to the KERS is 2.17 MJ, therefore more than the 2 MJ of the present rules, while the total energy flow to the wheels is 1.84 MJ. This translates in a fuel energy saving of 13.5%. Worth of note, with an electric KERS, the many additional energy conversions embedded reduce the charging and discharging efficiencies for round trip efficiency about 50% lower.

Fig. 12 is quite important, because tell us which KERS will be preferred in 2014 if the rules remain the same or if the rules will change:

If the F1 KERS has to be a strategic device as implicit in the present rules it will be electric. The energy stored in the battery does not reduce drastically with time and there is no need to reuse immediately the recovered energy of a braking event in the subsequent acceleration event.

If the F1 KERS has to be a fuel saving device, it will then be mechanical, but rules have to be modified for that. The round trip efficiency wheels – battery – wheels is at the most only one half of the round trip efficiency wheels – flywheel – wheels and more braking energy can be recovered with the mechanical KERS. However, the recovered energy of a braking event has to be preferably used in the subsequent acceleration event.

Without any doubt, the strategic KERS has no relevance for road racing. A small mechanical KERS fuel saving storing energy for a very limited time conversely will help considerably road car applications.

Considering the declared goal of the new rules is to go greener, we believe the best options would be to introduce a clear fuel consumption limit over the full race and then leave the research and development to work out the best devices needed to achieve this goal.

Worth of note, a F1 equipped with the 120 kW 0.3 MJ flywheel KERS of Fig. 12 and the turbo engine 475 kW of Fig. 3 to Fig. 6 would permit even faster lap times than today's F1 with not only the 13.5% less fuel energy of the KERS, but also the significant fuel saving of the novel small V6 1.6 litre engine about 27% more efficient than today's large V8 2.4 litre engines.

Fig. 13 presents the (conventional) power to and from the mechanical KERS vs. distance. The braking and propulsive powers are supposed to be unchanged with and without the KERS for same lap time. Fig. 14 presents the thermal energy with and without the mechanical KERS for same assumptions. These two pictures indicate at what distance is generated and spent the energy from KERS and therefore is necessary energy from the thermal energy, or the reduced thermal engine energy supply, but only for the same lap time, same total propulsive and braking powers on same weight car.

The much higher torque small turbo 475 kW engine coupled with a 120 kW fuel saving KERS will permit much sharper accelerations than today's low torque large naturally aspirated 525 kW engines practically without any KERS supply on a standard lap, with only a small penalty in top speed.

4 Lap time simulations

To quantify the effect of KERS a simulation was run using the race car simulation package ChassisSim. ChassisSim is fully transient lap time simulation software that is in current use in fields as diverse as GP2, F3, Sport cars, FIA GT, the ALMS and V8 Supercars. At the heart of ChassisSim is a highly detailed multi body vehicle model that can take into account a wide variety of performance parameters including KERS. The simulated data can also be exported to a wide variety of data analysis packages.

The KERS functionality in ChassisSim models the process of taking excess braking force at the rear and releasing this down the straight. Charge and discharge limits and efficiencies can be set as well as charge limits over the lap. The discharge can also be specified either down the start finish straight or distributed over the lap.

A GP2 car with equivalent F1 levels of acceleration was simulated at Barcelona with and without KERS. So that we are clear let us compare the two cars we are simulating. Table 1 presents the data of the 2 cars. Two different KERS are considered, the 400 KJ/60 kW of present F1 and the 2000 KJ/120 kW of future F1. The engine is a 4.0 L V8 of power output 456 kW at 10,000 rpm. The mass of the car is 688 kg. The charge and discharge limits are assumed to be both 60 kW for the present KERS and 120 kW for the future KERS. The charge and discharge efficiencies are both taken equal to 83.7% for the present KERS, as it is in the best mechanical KERS having a round trip efficiency approaching 70%. For the future KERS, the charge and discharge efficiencies are both taken equal to 89.4% for the future KERS, as it is in the best mechanical KERS being currently developed for passenger car applications having a round trip efficiency approaching 80%. The KERS is discharged every straight line. Front braking is assumed to be 50%. Only the energy stored in a lap is used in that lap (no strategic use, only continuous fuel saving use).

Table 1. GP2 car results

	Standard Car	With KERS 400 KJ/60 kW	With KERS 2 MJ / 120 kW
Mass	688 kg	728 kg	728 kg
KERS Energy	N/A	400KJ	2000 KJ
Charge/Discharge Limit	N/A	60 kW / 60 kW	120 kW/ 120kW
Charge/Discharge Efficiency	N/A	83.7% / 83.7%	89.4%/89.4%
Simulated lap time	1:27.707	1:28.480	1:27.720

The reason we have added 40 kg in weight is to simulate the weight we would have to add due to the KERS packaging. This is a known ball park figure but it can be a bit less. That being said we've included here as a yardstick. The charge and discharge limits have been chosen to represent current and future F1 regulations. The charge and discharge limits have been selected considering the best mechanical KERS built and being currently developed for passenger car applications. With the present KERS, while we have picked up speed in the straight, the extra weight has cost us in the corners leading to a lap time loss of 0.773 s, while the future KERS the lap time loss is a negligible 0.013 s.

Given the simple nature of this analysis this was to be expected. This analysis illustrates what KERS does very well, but also what you need to be aware of. On the positive side there is a very real and measurable increase in speed, which is ideal for either increased performance or to use when over taking another car. However this needs to be tempered with the knowledge that the weight increase of the car has to be factored and in order for the KERS to be effective it needs to be made as light as possible. There is an additional grip penalty. This also highlights how KERS can be a liability when it is not working. However one would fully expect as KERS systems evolve they will get lighter, more efficient and the grip penalty will also be reduced. This could open up a wide range of possibilities.

What this GP2 exercise tells us is that the KERS, certainly reducing the fuel consumption if used every deceleration and the following acceleration, may produce a penalty in the lap time for the grip (only the rear wheel excess grip recharge the KERS, the brake efficiency may therefore reduce) and the extra weight (only vs. the car without the KERS) weighting more than the increase in acceleration when discharging the KERS for present KERS. It is up to the novel rules certainly requiring some refinement to pave the area for a fuel energy saving KERS.

5 Conclusions

Small, high power density, turbocharged, premixed charge engines, with direct fuel injection of gasoline-like fuels and possibly throttle-less load control are certainly one of the best alternatives now available to improve the life cycle sustainability and environmental costs of road cars. Kinetic energy recovery systems permitting to recycle the braking energy during a deceleration to supplement the thermal energy supply of energy in a subsequent acceleration are also certainly a very important add-on of these engines to permit more environmentally friendly and fuel efficient transportation. Forcing the F1 teams to become greener pushing the small, high power density engine and the kinetic energy recovery systems technologies will certainly insulate the F1 sport from charges of wastefulness at a time when supplies of fossil fuels are diminishing and there is pressure for the world to cut its production of greenhouse gases.

Adoption of smaller 1.6 litre turbo charged engines, V-six; limited to 15,000 rpm, coupled to KERS having power doubled from 60 to 120 kW is not a reason to be concerned about the spectacle for itself. However, some of the ancillary rules like the caps on the amount of energy flowing through the KERS or the limit on the fuel flow rate to the engine may degrade the car performances and keep still high the fuel energy usage to cover a lap. However, more than the technical rules are the political rules made of cost reductions enforced through resource restriction only for what concerns research and development that make the chances of a penalized competition without any development of technologies of value for road cars quite realistic. The limits of freedom in F1 engines and power train research with the checks and balances to ensure costs are contained and performance across all engines remains comparable is not what is needed these days to make F1 really more relevant to road applications.

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