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Changes of E-KERS Rules to Make F1 More Relevant to Road Cars

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Abstract

Today's F1 hybrid cars are based on very similar power units made up of about the same internal combustion engine (ICE) and energy recovery system (ERS). Because of restrictive design rules permitting too much fuel per race, the internal combustion engine is not particularly fuel efficient. The methodology is based on lap time simulations and telemetry data for a F1 H car covering one lap of the Monaco Grand Prix. The methodology is based on lap time simulations and telemetry data for a F1 H car covering one lap of the Monaco Grand Prix. The present limit of 100 kg of fuel per race is excessive. The low power energy recovery system is used strategically rather than fuel savings recovering very little braking energy. The 4 MJ of storable energy is used only when it is strategically needed. The 2 MJ of recoverable energy allowed per lap are almost never collected. To return to be technically attractive, F1 should permit much more freedom in the definition of the ICE and the ERS. As the goal of the rules should be lowering the fuel consumption while keeping technical and sporting interest high, the best solution is more freedom to achieve the fastest car within more stringent limits of fuel economy. A real limit to the total fuel consumption for a race track like Monte Carlo should be not more than 80 kg of fuel. This would translate in more energy recovery to the ERS per lap and better fuel efficiency of the ICE and will certainly help more the design of passenger cars.

Keywords: hybrid cars, kinetic energy recovery systems, motorsport, F1, Le Mans

1. Introduction

Today F1 racing cars, similarly to other popular racing car series, are hybrid cars as the environmental concern must be at least apparently the driving force for every sport activity. The power unit now comprises an internal combustion engine and an energy recovery system. The energy recovery system in theory should recover the waste energy, mostly kinetic, to reduce the fuel energy supply to the internal combustion engine. Background information on kinetic energy recovery systems for racing cars can be found in [1], while the specific internal combustion engines and kinetic energy recovery systems (KERS) for 2014 F1 cars are discussed in [2-4]. The fuel saving goal is however practically eluded by the most part of the F1 teams. The kinetic energy recovery system is indeed mostly used strategically to boost the performance of a car, being, otherwise, the internal combustion engine not that powerful as it was in the recent past, by discharging the energy storage in selected lap and not certainly charging and discharging the energy storage every single lap.

The lack of freedom given to engineers to develop a technical solution delivering a target fuel economy is the reason why F1 is not technically challenging in a way that may be beneficial to road transport while being attractive to the motor enthusiasts. Purpose of the manuscript is to suggest changes of the technical regulations that could improve the energy

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recovery and the fuel conversion efficiency of the internal combustion engine for a better fuel economy while permitting top-class motorsport performances. It is shown how a more restrictive total fuel usage per race and more freedom to develop the internal combustion engine and the energy recovery system may benefit the interest towards the racing event and the value of the technical development for production cars.

2. LMP1-H vs. F1 hybrid 2015

The latest 2015 Le Mans race was dominated by the Porsches and the Audis battling until the very end of the race, with four class 1 Le Mans Prototype hybrid (LMP1-H) car manufacturers, the two German plus the Japanese Toyota and Nissan, proposing for the event very different technical solutions for what concerns the internal combustion engine (ICE), Diesel or Gasoline, different displacement, turbo or naturally aspirated, and the energy recovery system (ERS), electric or mechanic or electro-mechanic, of different powers and different energy storage. The rules set different limitations to the fuel flow rate per different ERS energy storage limits and fuel selection. These rules give the LMP1-H engineers the freedom to develop different ICEs and different ERSs. The developments of alternative solutions are ultimately what are needed to make the race event attractive to the motor enthusiast and be relevant, in long term perspective, to the design of every day passenger cars. The same technical enthusiasm does not certainly apply to todays' F1 hybrids. Ref. [4] provides an assessment of the different KERS options available in class 1 Le Mans Proto-type hybrid (LMP1-H).

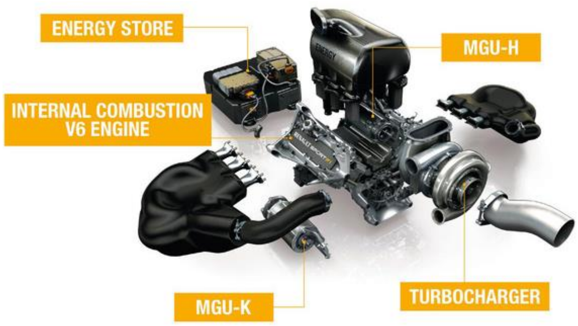


Fig. 1 F1 KERS (ES+MGU-K) and E-BOOST/WHR (ES+MGU-H) from [5]

Todays' F1 hybrids have power units where similarly to LMP1-H the ICE is one element of the power unit that also includes an ERS. Table 1 recalls the present specifications of the ICE and the ERS. The ERS includes two motor generator units (MGU) linked to an energy store (ES) recharged by the braking work and eventually the waste heat. The four power unit components, plus the ICE and the turbocharger are the six separate elements making a power unit. Four of each element are available to each driver per season without incurring in a grid penalty. During a race, drivers may use steering wheel controls to switch to different power unit settings, or to change the rate of ERS energy harvest. Fig. 1 (from [5]) presents the F1 KERS (ES+MGU-K) and E-BOOST/WHR (ES+MGU-H).

The set-up of the power unit of a F1 hybrid is therefore in principle not that far from the one of the Porsche 919 H winner of the last Le Mans 2015 race. The difference is, however, substantial when the details are considered. F1 is much better for what concerns the turbocharger, as the MGU-H fitted to the turbocharger shaft and connected to the ES gives wider opportunities than having just a power turbine downstream of the traditional turbocharger turbine to recover a minimal amount of waste heat at the expenses of increased back flow. However, F1 hybrids are less flexible under all the other aspects.

In F1, the turbocharged 1.6-litre V6 engines are pretty much the same for every team. Not only same displacement and (about) same fuel, but also same number of cylinders, same 90-degree V angle, same rev limiter at 15,000 rpm, same four poppet valves per cylinder, same direct fuel injection, same single fixed geometry turbocharged, same bore, same stroke, same crankcase height, almost everything the same to deliver about the same 600 HP or 447 kW of top brake power, with brake mean effective pressure and brake specific fuel consumption curves also expected to be very similar.

The 600 HP or 447 kW are the values of peak power claimed by the most part of the teams for the 2014 season. The fuel flow rate is limited to 100 kg/h, that considering a lower heating value for gasoline of 44.5 MJ/Kg translates in a maximum fuel power of 1236 kW or 1658 HP, for a peak power efficiency of the ICE of 600/1658 = 36.2%. Per rumors, a couple of teams outperforming the others this 2015 season could have moved around this limit prompting the federation to seek for remedy. If the fuel flow meter is placed in a certain location of the fuel line, there is always the opportunity to accumulate fuel downstream of the flow meter, and, therefore, enjoy an instantaneous flow rate delivered by the high-pressure fuel injectors more than the instantaneous contemporary reading of the ambient pressure flow meter flow rate.

Table 1 Data of power units of 2015 F1 hybrid cars

Internal Combustion Engine	
Displacement	1.6 liters
Rev limit	15,000 rpm
Pressure charging	Single turbocharger, unlimited boost pressure (but maximum 3.5 bar due to fuel flow limit)
Fuel flow limit	100 kg/h (but not at the injectors)
Permitted Fuel quantity per race	100 kg
Configuration	90° V6
Number of cylinders	6
Bore	80 mm
Stroke	53 mm
Crank height	90 mm
Number of valves	4 per cylinder, 24 total
Exhausts	Single exhaust outlet, from turbine on car center line
Fuel	Direct fuel injection
Number of Power Units permitted per driver per year	5
Energy Recovery Systems	
MGU-K rpm	Max 50,000 rpm
MGU-K power	Max 120 kW
Energy recovered by MGU-K	Max 2 MJ/lap
Energy released by MGU-K	Max 4 MJ/lap
MGU-H rpm	unlimited
Energy recovered by MGU-H	unlimited

Every percentage point increment of the ICE fuel conversion efficiency everything but difficult to achieve would translate in an increase of the peak power of 12 kW or 17 HP. Similarly, any percentage increase of the instantaneous flow rate to the injectors would translate in an increment of the instantaneous peak power of 4.5 kW or 6 HP. As an additional measure to temporarily increase the peak power, the MGU-H can drive the turbocharger compressor that, otherwise, only depends on the gas expansion through the turbine that is also translating in back pressure for the engine. This can make plausible the larger peak power outputs rumored for 2015.

In addition to the maximum fuel flow rate, below 10,500 rpm the fuel mass flow must not exceed $Q = 0.009\ N + 5.5$, with N the engine speed in rpm and Q in kg/h. In addition to the fuel flow limiter placed along the fuel line, the 2014 and 2015 season have seen the introduction of a total fuel per race capped at 100 kg, or 4,450 MJ of fuel energy per race, that is certainly a driver for much better fuel economies, but not certainly that strong. This fuel limit properly redefined may be the driver for a better product.

Fully integrated with the ICE is the ERS that increases the unit’s overall efficiency by recovering the waste energy from the brakes and the exhaust. The recovery of the exhaust energy is, however, simply the turbocharger turbine that may deliver energy to the energy store that is not delivered to the turbocharger compressor. The ERS accounts for an additional 120 kW or 160 HP to deliver about the same power output of the past 2.4 liters V8 engines naturally aspirated. The ERS comprises two motor generator units (MGU-K and MGU-H), plus the energy store. The motor generator units convert mechanical and heat energy to electrical energy and vice versa. The MGU-K converts the car kinetic energy generated under braking into electricity while it acts as a motor under acceleration returning power to the drivetrain. The MGU-H converts the exhaust heat into electricity but only through the turbocharger, i.e. only recovers the very small amount of energy in the turbine that would be otherwise waste-gated when more than the compressor demands. The stored energy can be used to power the MGU-K. The MGU-H controls the speed of the turbo and the power from to and from the turbocharger shaft. The MGU-H may supply the extra energy needed at the compressor when the turbine energy is not enough, as for example in low speed operating points or during accelerations, in this case ad-dressing the turbolag issues. It may also recover the extra energy available at the turbine otherwise waste-gated. The MGU-H may increase the power of the ICE at any speed by precise extra boost, operating in the best point of the map, with supply or withdraw of extra energy. While the E-Boost technology is certainly not new [10-15], the precise boost of the F1 MGU-H linked to the ES of the KERS may certainly improve the overall power and energy management of the vehicle.

Apart from the same design of the MGU and ES purely electric, are the energy and power limits of the ES and the MGU-K that makes a huge difference vs. the LMP1-H cars. While LMP1-H cars have maximum released energy of 2, 4, 6 or 8 MJ/lap and unlimited released power, in F1 a maximum of 4 MJ per lap can be transferred from the ES to the MGU-K and then the drivetrain, but only a maximum of 2 MJ per lap can be transferred from the MGU-K to the ES. More than that, the maximum power of the MGU-K is limited to only 120 kW or 160 HP, while the LMP1-H all have powers of the MGU-K more than 185 kW up to a maximum of 550 kW considered for the Nissan GT-R LM NISMO. The low power in addition to the limited energy is what makes the fuel saving kinetic energy recovery very difficult.

As braking of F1 cars usually occurs with powers largely exceeding the propulsive power, up to about 2,000 kW the low power MGU-K must be recharged carefully, as this recharge translates in a lap time penalty. In F1, the MGU-K is limited to recover 2 MJ of energy per lap while the MGU-K may then supply a maximum of 4 MJ per lap to the drivetrain but the maximum power in and out is limited to 120 kW (160 HP). This means that the ERS is more strategic rather than energy saving, as it can be certainly used to save or gain positions or improve the time of an individual lap, while it is still not convenient and not encouraged to recover and reuse the braking energy at any lap as it would be the case if the fuel energy saving would be the real issue.

Table 2 Summary table of 2015 LMP1-H and F1-H power and energy rules
(a) limited to <300 kW in 2016. (b) no driver. (c) with driver

LMP1-H (Le Mans race track)							F1-H
		No ERS	ERS OPTIONS				
Released Energy	MJ/Lap	0	< 2	< 4	<6	< 8	<4
Recovered Energy	MJ/Lap	0					<2
Released Power	kW	0	unlimited(a)	unlimited(a)	unlimited(a)	unlimited(a)	120 kW
Car Mass	kg	850(b)	870(b)	870(b)	870(b)	870(b)	702(c)
Petrol Energy	MJ/Lap	150.8	146.3	141.7	137.2	134.9	
Max Petrol Flow	kg/h	95.6	93	90.5	87.9	87.3	100
Petrol capacity carried on-board	l	66.9	66.9	66.9	66.9	66.9	
Fuel Technology Factor	-	1.061	1.061	1.061	1.061	1.061	NA
K Technology Factor	-	1	0.983	0.983	0.983	1	
Diesel Energy	MJ/Lap	142.1	140.2	135.9	131.6	127.1	
Max Diesel Flow	kg/h	83.4	83.3	81	78.3	76.2	
Diesel capacity carried on-board	l	54.8	54.8	54.8	54.8	54.8	

Table 2 presents a summary of the 2015 LMP1-H and F1-H power and energy rules. In case of one lap of the Monaco Grand Prix, 3.337 km long, a F1 of curb weight 702 kg less the driver weight may use 1.28 kg or 57 MJ of fuel energy, i.e. 17 MJ/km. In case of one lap of the Le Mans race, the Circuit de la Sarthe is 13.629 km long; a LMP1-H of curb weight 870 kg may only use 134.9 MJ of fuel energy, i.e. 9.9 MJ/km.

Even if it is not desirable for energy saving to switch on the MGU-K at end of straight for a small-time interval before the driver hits the friction brakes, this is what presently makes the largest contribution to the amount of energy available to the ES in F1. The overall lap time may also be faster with this strategic recharge because of the faster acceleration up to speed on the next straight may more than compensates for the lost time. This technique is not, however, in the direction of improving the fuel economy, as the direct path engine to wheels is much more efficient than the path engine to MGU-K to ES to MGU-K to wheels.

The MGU-H is in theory uncapped, and an unlimited amount of energy can be transferred between the MGU-H and the ES and/or the MGU-K. The MGU-H technology is still far from being fully developed, but it is expected to help more in terms of ICE output by precise boost rather than recovery of waste heat. The use of MGU-H and MGU-K and ES may permit further enhanced energy and power management.

3. Energy analysis of a F1 2015 lap of Monte Carlo

To understand the present status of energy recovery and fuel economy, telemetry and lap time simulations may help. The selected race track is Monte Carlo. The Circuit de Monaco is a street circuit of length 3.34 km. The total distance is 78 laps or 260.52 km.

If we do consider the last 5 years of the Monte Carlo competition, 3 with the naturally aspirated 2.4 liters V8 and a very small MGU-K of 60 kW, and the latest 2 with the turbocharged 1.6 liters V6 with the larger but still small present MGU-K of 120 kW, clearly the latest F1 are much slower than their predecessors no matter the claim of preserving the maximum power output to preserve performances. In 2011, with sunny, fine and dry conditions, the best qualifying time for pole position was 1:13.556 while the fastest lap during the race was 1:16.234. In 2012, with warm and sunny conditions, about same fine conditions except the threat of showers at the end of the race, the best qualifying time for pole position was 1:14.381 while the fastest lap during the race was 1:17.296. In 2013, with sunny and dry conditions, the best qualifying time for pole position was 1:13.876 while the fastest lap during the race was 1:16.577. During the first season with the new rules, in 2014 with sunny and dry conditions, the best qualifying time for pole position was 1:15.989 while the fastest lap during the race was 1:18.479, roughly 2 seconds slower. Finally, this year, 2015, with sunny and dry conditions, the best qualifying time for pole position was 1:15.098 while the fastest lap during the race was 1:18.063. Therefore, the new rules have certainly slowed down the cars. Some improvements have however been achieved in terms of fuel economy, even if the 100 kg of maximum fuel per a race is not yet the driving force for the further development of the ICE and the ERS to drastically reduce the fuel consumption.

Telemetry and lap time simulations may be used to compute the likely performances of F1cars during one lap. The dynamic of racing cars and the equations governing the motion of the car are proposed in [6]. The specific software used in this paper, [7], is very simple but reliable. Not having too much of supporting information as detailed digitized telemetry data and vehicle parameters, more complicated approaches as for example [8] only introduces additional difficulties to define the many other additional parameters involved in the simulation. The code [7] solves the Newton's equations of motion in the three directions for a point moving along a curved path.

The minimum weight of the car including the driver but not the fuel was 690 kg in 2014 and it is 705 kg in 2015. The weight of the car is, therefore, taken here equal to 720 kg. For what concerns the aerodynamic drag, we approximate the aerodynamic drag force as $½·ρ·v2· CD·A$, where ρ is the air density, CD is the drag coefficient and A is the frontal car area, and the lift force as $½·ρ·v2· CL·A$ where CL is the lift coefficient. We take ρ=1.29 kg/m3, CD=0.85 and CL=2.4 when A=1.5 m2 for the specific very low speed circuit. As the drag force dramatically impact on the energy requested by a F1 car to cover a lap, the above far from accurate values certainly impact on the accuracy of the energy computation.

The simulations require definition of few additional parameters, as the tires radius, the lift (downforce) coefficient, the rolling resistance and the longitudinal and lateral friction of tires, the gear ratios of the sequential gearbox, the final drive ratio, the drive efficiency and a grip ratio, in addition to the specification of the engine power curve and obviously of the race track.

While some of the latest lap time simulation codes as [8] also account for lateral and longitudinal weight transfer, real tire effects as camber, slip ratio and slip angle, temperature and pressures, vehicle yaw over-steering or under-steering and, finally banking and grade on the track, the code [7] does not.

Today's most sophisticated lap time simulation tools are fully integrated with the vehicle management and data acquisition systems. While these tools are very accurate, they also rely on the in-deep knowledge of the detailed vehicle operation that is proprietary data of only the teams. Without this in-deep knowledge, they are only more complicate without being more accurate than [7].

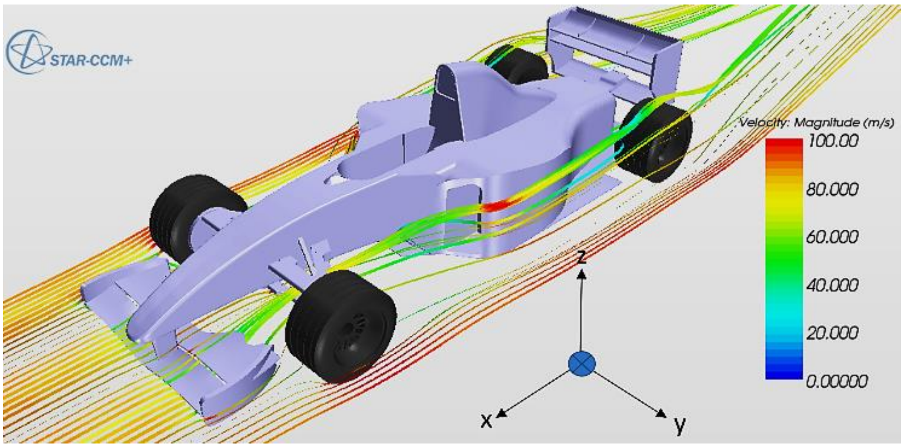
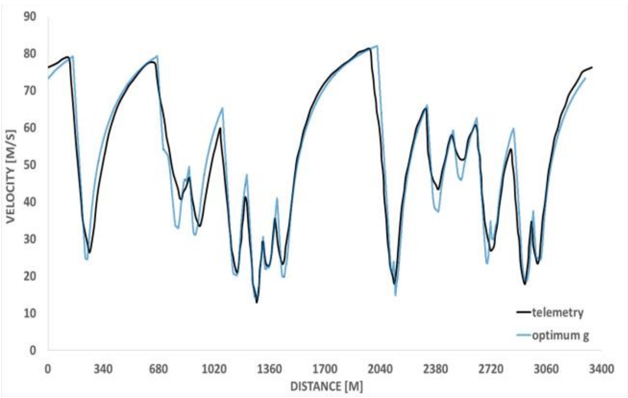
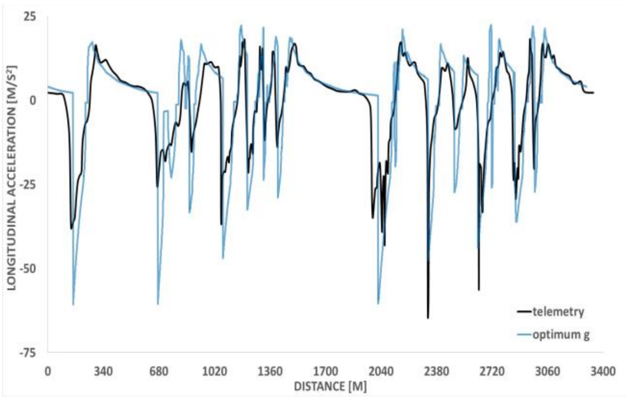


Fig. 2 Lump mass model of a F1 car

Fig. 2 presents the lump mass model of a F1 car. The three-dimensional computation of the car aerodynamic with moving wheels and ground is proposed in [9]. The aerodynamic simulations return drag and lift coefficients to be used in the model. The car is modelled as a particle moving along a curved path subject to propulsive and braking forces. This simplified model permits a straightforward evaluation of the energy flow of the car covering one lap of a race track. The Newton's equations of motion are solved for the longitudinal, lateral and vertical directions.



(a) Velocity vs. distance of a F1 car

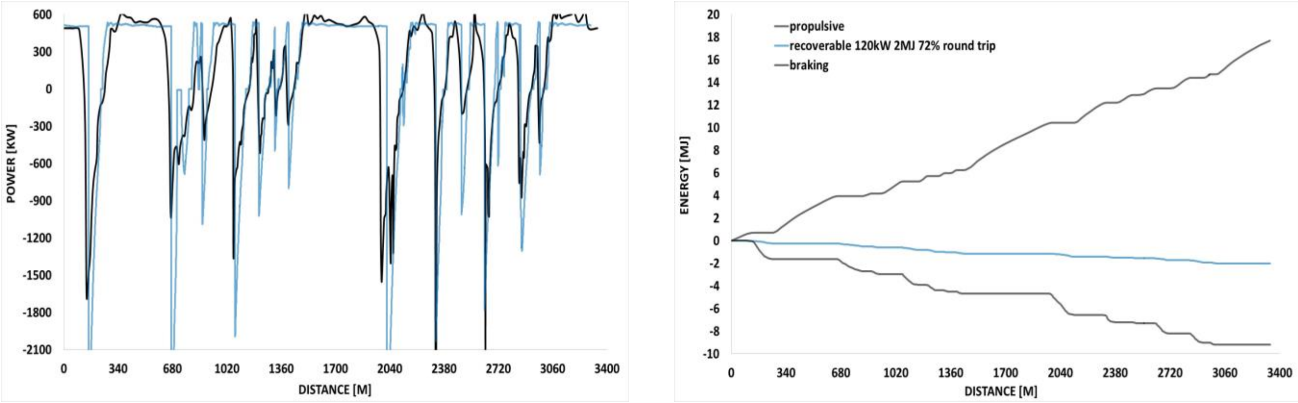


(b) Longitudinal acceleration vs. distance of a F1 car

Fig. 3 Velocity and longitudinal acceleration vs. distance of a F1 car covering one qualifying lap at Monte Carlo

Fig. 3(a) presents the velocity vs. distance from telemetry and from the simulation, and Fig. 3(b) presents the longitudinal acceleration. The telemetry information was digitized from an image, and, therefore, suffers of poor resolution. Lap time is 1:15:100. This optimum lap is covered by using the ICE and the electric energy

The simulation produces one velocity value every half a meter of the race track, but the differences in between the two traces are not only due to the different resolution, but also to the model not fully tunable by lack of knowledge of the vehicle parameters and limited by the simplified mathematics. The lap time is 1:15:100. This optimum lap is covered by using 13 MJ of ICE fuel energy delivered with up to a power of 450 kW depending on engine speed plus 4 MJ of electric energy delivered with up to a power of 120 kW.



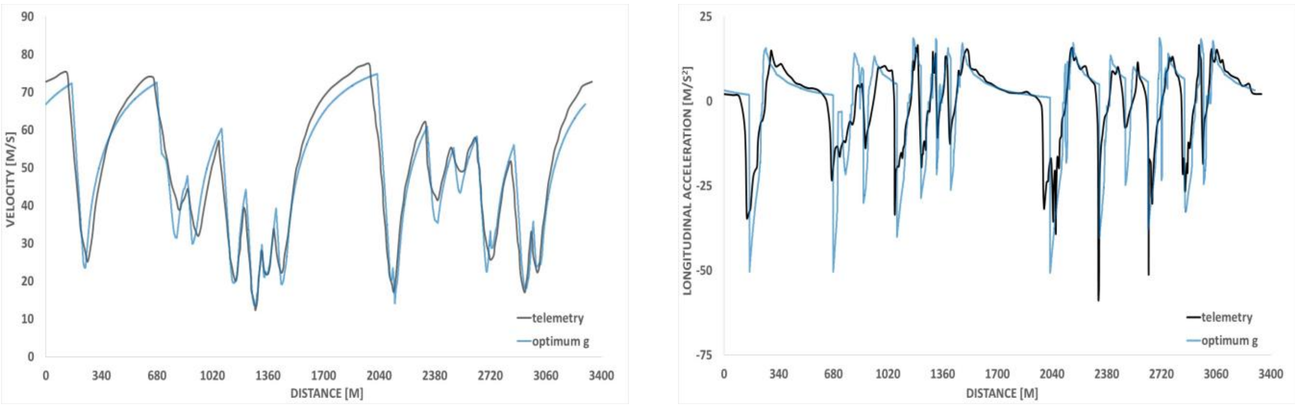
(a) Propulsive vs. distance of a F1 car

(b) Braking powers and propulsive, braking and recoverable energy vs. distance of a F1 car

Fig. 4 Propulsive and braking powers and propulsive, braking and recoverable energy vs. distance of a F1 car covering one qualifying lap at Monte Carlo

Figs. 4(a) and 4(b) present the propulsive and braking powers and propulsive, braking and recoverable energy vs. distance of a F1 car covering one lap at Monte Carlo as detailed in Fig. 3. Lap time is 1:15:100. This optimum lap is covered by using the ICE and the electric energy. The propulsive energy is 17.69 MJ; the braking energy is 9.20 MJ and the theoretically recoverable energy is 1.99 MJ.

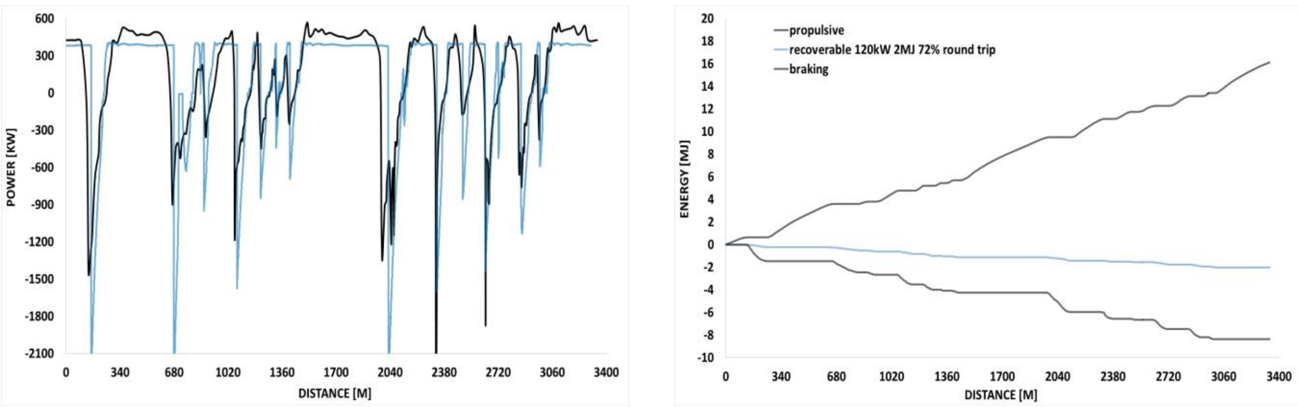
The graphical comparison of telemetry and model results shows a good accuracy. This comparison is usually enough for this kind of simulations and perfectly aligned with the scope of the paper aimed to discuss changes of rules rather than the accuracy of lap time simulations.



(a) Velocity vs. distance of a F1 car

(b) Longitudinal acceleration vs. distance of a F1 car

Fig. 5 Velocity and longitudinal acceleration vs. distance of a F1 car covering one standard race lap at Monte Carlo



(a) Propulsive vs. distance of a F1 car

(b) Braking powers and propulsive, braking and recoverable energy vs. distance of a F1 car

Fig. 6 Propulsive and braking powers and propulsive, braking and recoverable energy vs. distance of a F1 car covering one standard race lap at Monte Carlo

Figs. 5 and 6 present same results of Fig. 3 and 4 with a different set up permitting 1.6 s slower lap times. In Fig. 5, lap time is 1:18:700. This lap is covered by using the ICE energy only. The grip is reduced 9% vs. the qualifying conditions reflecting tire usage. In Fig. 6, lap time is 1:18:700. This lap is covered by using the ICE energy only. The grip is reduced 9% vs. the qualifying conditions reflecting tire usage. The propulsive energy is 16.12 MJ; the braking energy is 8.38 MJ and the theoretically recoverable energy is 2.00 MJ.

4. Discussion

Traditional limiting factors for the MGU-K braking energy recovery are the power of the unit, the total energy storage, the balance in between the front and rear axle braking and the balance in between MGU-K and friction braking. Certainly, energy storage at powers much higher than 120 kW also has some downfall for an F1 car. The aero drag is so huge that there is much less energy available at very high vehicle speeds. Furthermore, the very high energy numbers only last for a fraction of second. However, the much higher power and energy storage limits permitted in the LMP1-H series certainly show the way to move. If the energy input from the MGU-K to the ES may not exceed 2MJ in any one lap and energy released from the ES to the MGUK may not exceed 4MJ in any one lap, this means that the continuous use of the KERS is eventually limited to just the 2MJ 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. This does not help the fuel economy.

From a global fuel energy perspective, the total fuel available to cover the 78 laps or 260.52 km in Monte Carlo is 100 kg. This translates roughly in 1.28 Kg per every lap of 3.34 km. By assuming a lower heating value for gasoline of 44.5 MJ/Kg, this translates in a maximum fuel energy supply of 57.0 MJ per lap. The power unit energy requested per lap is less than 16.1 MJ. This translates in an average fuel efficiency of only 28.2% requested to the engine without any working kinetic energy recovery. By recovering the 2 MJ per lap with the MGU-K, this efficiency could be further reduced to an even smaller 24.7%. These efficiencies are everything but great.

While better estimations may certainly follow the use of the telemetry data and the lap time simulations tools the teams do have, when considering the 1.5 liters V6 turbo engines of the previous turbo era almost 30 years ago were already operating with efficiencies well above 30% in a range of operating points of interest, it does not seem that the 100 kg per race is a really an up-to date limit set to push forward the boundaries of energy efficiency, as the teams may easily achieve the 28.2% efficiency and avoid recovering the braking energy in normal laps, recharging the ES only strategically and using the MGU-K only when needed to gain/defend a position.

The previous analyses are done without any inclusion of the Drag Reduction System (DRS). This overtaking aid permits a driver within one second of a rival car within designated DRS activation zones to alter the angle of the rear wing flap, reducing drag coefficient and thereby achieving a temporary speed advantage. The DRS has no relevant impact on the fuel economy.

Regarding the energy flow through the MGU-H, any transformation of energy type, for example mechanical to electrical to chemical back to electrical and back to mechanical occurs with efficiency far from unity.

How powerful is today's power unit of hybrid F1 when compared with traditional powertrains of the past is a question difficult to answer. For marketing purposes, it is common to claim that today's power units have the peak power of the ICE, plus the peak power of the MGU-K, with the MGU-H possibly further increasing the power of the ICE by precise extra boost. The ICE delivers power to the wheels as a function of the speed of the crankshaft. The 450 kW of peak power are obtained at high speeds approaching the speed limiter and certainly not at low speeds. The MGU-K also delivers power to the wheel, but the 120 kW of peak power are now available at any speed of the crankshaft.

The best use of the MGU-K is to produce a faster acceleration after a bend and not to increase the top speed on a straight. The MGU-H of untapped power does not deliver any power to the wheels. The MGU-H is only linked to the turbocharger, and may only help the ICE to deliver more power by spinning faster the turbine above the balance in between gas expansion in the turbine and air compression in the compressor. If the MGU-K power is supplied at low speed, then the equivalent torque of the engine drastically improves.

Today's power unit of hybrid F1 are by far less powerful of past traditional powertrains, but certainly have much better torque.

5. Conclusions

To return to be technically attractive, F1 should permit much more freedom in the definition of the ICE and the ERS. As the goal of the rules should be the lowering the fuel consumption while keeping high the technical and sporting interest, the best solution is more freedom to achieve the fastest car within more stringent limits of fuel economy. This would benefit the racing and the everyday car.

A real limit should be set to the maximum amount of fuel to be used for a fixed distance race, and the engineers should be, then, left free to develop the hybrid power unit with at the most a prescribed displacement of the engine. The present limit of 100 kg of fuel per race does not force the teams to recover the 2 MJ of energy every lap, and does not force them to use the fuel much more efficiently within the internal combustion engine that what is common practice since decades.

A real limit to the total fuel consumption for a race like Monte Carlo should be not more than 80 kg of fuel, that would require the recovery of the 2 MJ of energy every lap and an average fuel efficiency of the ICE of 30.9%, everything but impossible to reach with today's technologies, but certainly much better than what is presently delivered by today's F1 internal combustion engines. Alternatively, the teams could continue to use only strategically the MGU-K not as a fuel saving measure, but they should, then, improve their internal combustion engines to an average fuel efficiency of 35.2%. These numbers will certainly need the development of novel strategies that may help the design of passenger cars.

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Definitions/Abbreviations

a	acceleration	LMP1-H	Le Mans Prototype 1 Hybrid
E	energy	m	mass
E-KERS	Electric KERS	MGU	motor-generator unit
ERS	energy recovery system	MGU-K	driveline MGU
ES	energy store	MGU-H	turbocharger MGU
F	force	P	power
ICE	internal combustion engine	R	force
KERS	Kinetic Energy Recovery Systems	v	velocity