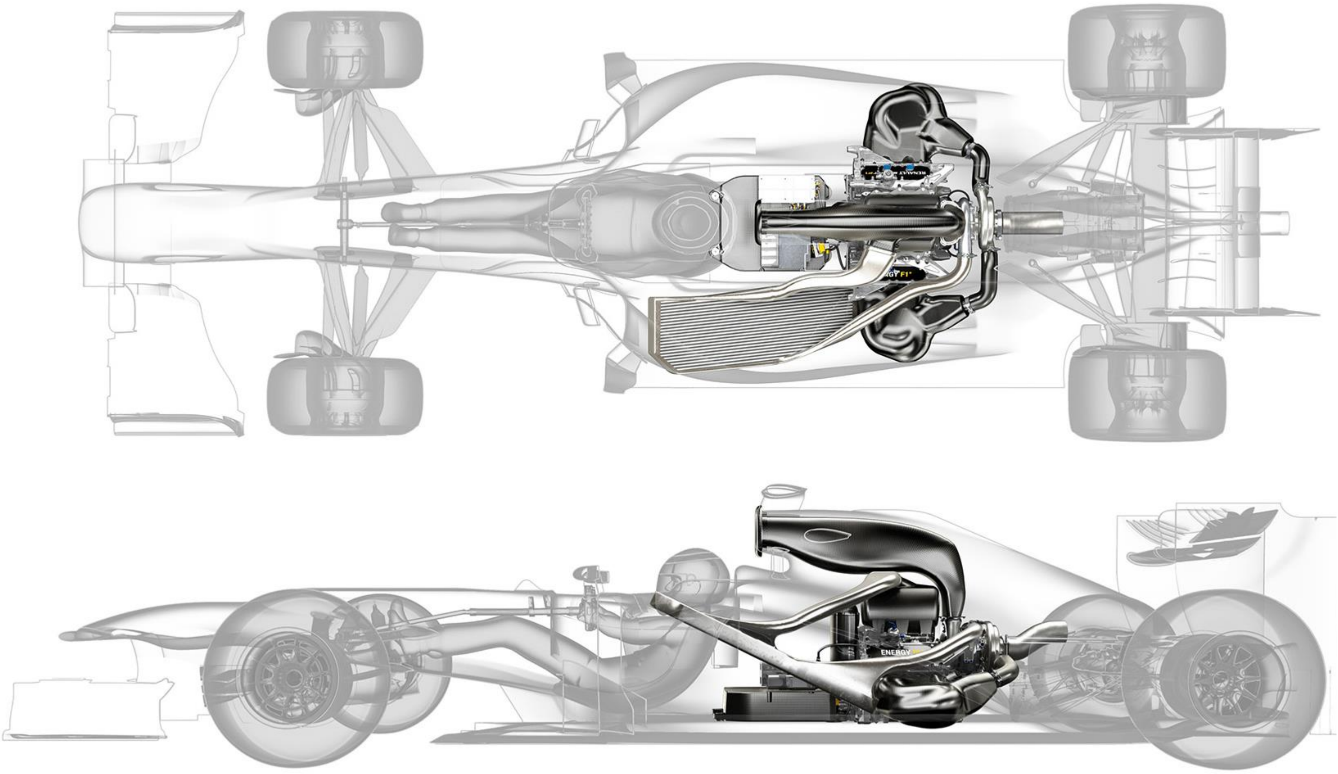
F1-Forecast Predict the Race

THE F1-FORECAST.COM TECHNICAL FILES

THE FORMULA 1 HYBRID POWER UNITS 2014-2015



F1 Season 2015 | Dominique Madier

www.f1-forecast.com

In the same category, you can download the following F1-Forecast Technical Files in the Section "F1-Technology" of http://www.f1-forecast.com :

The F1-Forecast Technical Files

F1 Season 2015 Volume II – Aerodynamic & Mechanical Updates – Complete Season
by Dominique Madier
1400 pages

F1 Season 2015 Volume I – F1 Cars 2015 Presentation & Winter Tests
by Dominique Madier
360 pages

F1 Season 2014 Volume II – Aerodynamic & Mechanical Updates – Complete Season
by Dominique Madier
1070 pages

F1 Season 2014 Volume I – F1 Cars 2014 Presentation & Winter Tests
by Dominique Madier
450 pages

F1 Season 2013 Volume III - Aerodynamic & Mechanical Updates (from Canada to Brazil)
by Dominique Madier
870 pages

F1 Season 2013 Volume II - Aerodynamic & Mechanical Updates (from Australia to Monaco)
by Dominique Madier
750 pages

F1 Season 2013 Volume I – F1 Cars 2013 Presentation & Winter Tests
by Dominique Madier
750 pages

F1 Season 2011 - Aerodynamic & Mechanical Updates
by Dominique Madier
700 pages

F1 Season 2010 - Aerodynamic & Mechanical Updates
by Dominique Madier
630 pages

F1 Season 2009 - Aerodynamic & Mechanical Updates
by Dominique Madier
450 pages

TABLE OF CONTENTS

1. Introduction

The 2015 season has been the second year of use of the hybrid power units of Formula 1. Since 2014, many changes were introduced by the engine manufacturers. In 2015, Honda joined Mercedes, Ferrari and Renault in the race to develop these new ultra sophisticated power units. After a 2014 season dominated by Mercedes in terms of pure power and energy recovery, Ferrari seems to have caught the star brand following the developments of the 2015 season.

In the F1 paddock a rumor even says that the F1 power unit of men from Maranello would be almost at the level of Mercedes. But the Ferrari engineers know they must continue developing their engine this winter because the star brand is not going to stop in the armaments race so engaged. Mercedes has still kept a slight advantage over Ferrari throughout the season 2015 thanks to a very well born 2014 engine that still has a considerable development potential. But what will it be in 2016?

Renault, meanwhile, still seems to look for solutions to its power unit to reveal all its qualities. The return of the parent Renault F1 as a full-fledged constructor in 2016, should allow men from Viry-Châtillon back on the path of victory (if not in 2016, it will likely be in 2017) .

Honda finally faced the teething problems of a power unit old of only one season while the other engine manufacturers are already in their second year of development. We bet that engineers at Honda will return to the path that will lead the Japanese brand in the vanguard.

This document is intended to introduce, at first, the concept of hybrid power units of Formula 1. As you will see, these power units are extremely complex.

We then turn to the chapter of integration and architecture of engines in 2014. Based on the concepts changes in the 2015 season will then be addressed through a chapter that reviews the new concepts introduced by the four engine manufacturers.

The information presented in this document come from the following sources:

- ✓ Race Car Engineering: http://www.racecar-engineering.com
- ✓ Nicolas Carpentiers from F1i: http://www.f1i.com
- ✓ YouTube videos

Dominique Madier
Webmaster F1-Forecast.com
Montreal – Canada – March 2016

2. How Formula One's Amazing New Hybrid Turbo Engine Works?

The 2014 Formula 1 season has been defined by the introduction of advanced new hybrid engines. These new power units are built around a 1600cc turbocharged V6 with direct fuel injection. But that really only the tip of a very big and complex iceberg.

The engines have a double restriction on fuel consumption which will really change everything. In 2014 they will have cover a grand prix distance using 35% less fuel, with a maximum fuel load of 100kg (not the same as 100 litres). On top of that the rate of fuel flow is also limited to 100kg/hour. Now it does not take a scientist to work out that at the maximum flow rate the cars could not finish the race. So other strategies must be employed. This is where the 'double hybrid' system comes in.

The power units are fitted with two electric motors, one linked directly to the turbocharger, the other working in the same was that KERS MGU's have done in the past. The combined maximum power output will be around 760bhp similar to the output of the rev limited V8's of 2013.

But the make up of these power units is both complex and fascinating.

The Engine

The major components of the 1600cc turbocharged V6.

All of the cars in F1 are fitted with 1.6 litre turbocharged engines in 2014, Ferrari, Mercedes and Renault between them supply all of the teams until 2015 when Honda arrives to supply McLaren.

The engines are six cylinder units arranged in a V, the exact same principle found in many production cars such as the smaller engined Ford Mustangs for example. In Formula 1 specifications the engines will make around 600bhp, which in pure output terms does not sound like all that much, it is only about 150bhp more than a World Rallycross Championship car produces for example. But the F1 engines are far more efficient, smaller and much lighter.

But engine designers from the likes of Ferrari, Honda, Mercedes and Renault should have no problem creating an engine that can produce this performance after all both Ferrari and Mercedes produce street cars with more power.

"Contrary to popular belief, the engine is not the easiest part of the Power Unit to design as the architecture is very different to the old V8s. On account of the turbocharger the pressures within the combustion chamber are enormous – almost twice as much as the V8. The crankshaft and pistons will be subject to massive stresses and the pressure within the combustion chamber may rise to 200bar, or over 200 times ambient pressure" explains a Renault engineer. "The pressure generated by the turbocharger may produce a 'knocking' within the combustion chamber that is very difficult to control or predict. Should this destructive phenomenon occur, the engine will be destroyed immediately."

This we are told by just about everyone in the F1 paddock, will happen in the 2014 season, quite a lot.

Fuel Injection

All Power Units must have direct fuel injection (DI), where fuel is sprayed directly into the combustion chamber rather than into the inlet port upstream of the inlet valves. The fuel-air mixture is formed within the cylinder, so great precision is required in metering and directing the fuel from the injector nozzle. This is a key sub-system at the heart of the fuel efficiency and power delivery of the power unit.

One of the central design choices of the ICE was whether to make the DI top mounted (where the fuel is sprayed at the top of the combustion chamber close to the spark plug) or side mounted (lower down the chamber). Nobody has revealed which option they have gone for – yet.

Interestingly the option still remains to cut cylinders to improve efficiency and drivability through corners. Not quite traction control but not far off it.

Turbocharger

A turbocharger uses exhaust gas energy to increase the density of the engine intake air and therefore produce more power. Similar to the principle employed on roadcars, the turbocharger allows a smaller engine to make much more power than its size would normally permit. The exhaust energy is converted to mechanical shaft power by an exhaust turbine. The mechanical power from the turbine is then used to drive the compressor, and also the MGU-H.

At its fastest point the turbocharger is rotating at 100,000 revolutions per minute, or over 1,500 times per second, so the pressures and temperatures generated will be enormous. Some of the energy recovered from the exhaust will be passed on to the MGU-H and converted to electrical energy that will be stored and can later be re- deployed to prevent the turbo slowing too much under braking.

As the turbocharger speed must vary to match the requirement of the engine, there may be a delay in torque response, known as turbo lag, when the driver gets on the throttle after a period of sustained braking. One of the great challenges of the new power unit is to reduce this to near zero to match the instant torque delivery of the V8 engines.

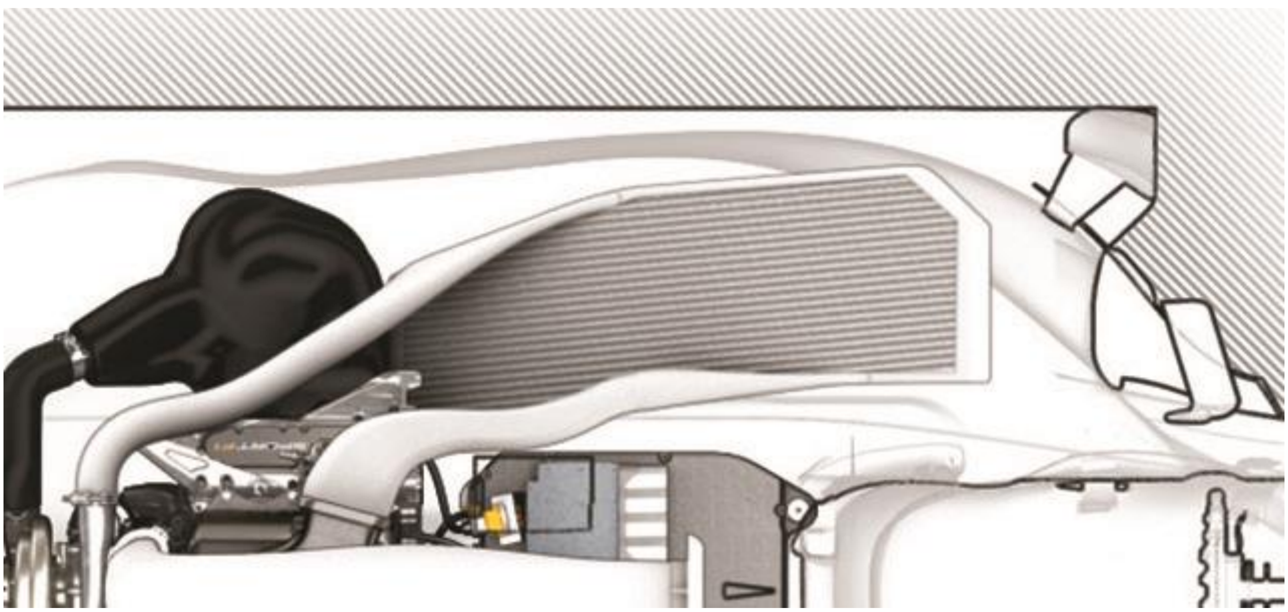
Wastegate

On conventional turbo engines, a wastegate is used in association with a turbocharger to control the high rotation speeds of the system. It is a control device that allows excess exhaust gas to by-pass the turbine and match the power produced by the turbine to that needed by the compressor to supply the air required by the engine. On the F1 engines, the turbo rotation speed is primarily controlled by the MGU-H (see the hybrid section) however a wastegate is needed to keep full control in any circumstance (quick transient or MGU-H deactivation).

"The wastegate is linked to the turbocharger but sits in a very crowded area of the car. The challenge is therefore to make it robust enough to withstand the enormous pressures while small enough to fit" explains the Renault engineer. "On a plane there are certain parts that are classified as critical if they fail. By this measure the wastegate is the same: if it fails the consequences will be very serious."

Intercooler

The intercooler is used to cool the engine intake air after it has been compressed by the turbocharger. The presence of an intercooler (absent in the normally aspirated V8 engines), coupled with the increase in power from the energy recovery systems makes for a complicated integration process since the total surface area of the cooling system and radiators has significantly increased over 2013.



Indeed the availability of F1 specification radiators is currently nil, due to the many changes and updates made by teams over the winter. This has prevented at least one team making it to the first test. Integration of the intercooler and other radiators is key but effective cooling without incorporating giant radiators is a major challenge and key performance factor in aerodynamic terms.

The Hybrid System

Energy efficiency will reach levels never seen in the sport before, with two types of energy propelling the cars. The internal combustion engine will produce power through consumption of traditional carbon-based fuel, while electrical energy will be harvested from exhaust and braking by two motor generator units. The two systems (MGU-H & MGU-K) will work in harmony, with teams and drivers balancing the use of the two types of energy throughout the race.

MGU-K

The MGU-K is connected to the crankshaft of the internal combustion engine, generally mounted underneath the oil tank in a recess at the back of the chassis – seen here on the Red Bull RB9

Under braking, the MGU-K operates as a generator, recovering some of the kinetic energy dissipated during braking. It converts this into electricity that can be deployed throughout the lap (limited to 120 kW or 160bhp by the rules). Under acceleration, the MGU-K is powered from the Energy Store and/or from the MGU-H and acts as a motor to propel the car.

Whilst in 2013 a failure of KERS would cost about 0.3s per lap at about half the races, the consequences of a MGU-K failure in 2014 would be far more serious, leaving the car propelled only by the internal combustion engine and effectively uncompetitive.

Thermal behaviour is a massive issue as the MGU-K will generate three times as much heat as the V8 KERS unit, in 2013 KERS units regularly suffered failures when track temperatures exceeded 40C. The cooling of these systems could become one of the key performance differentiators in 2014.

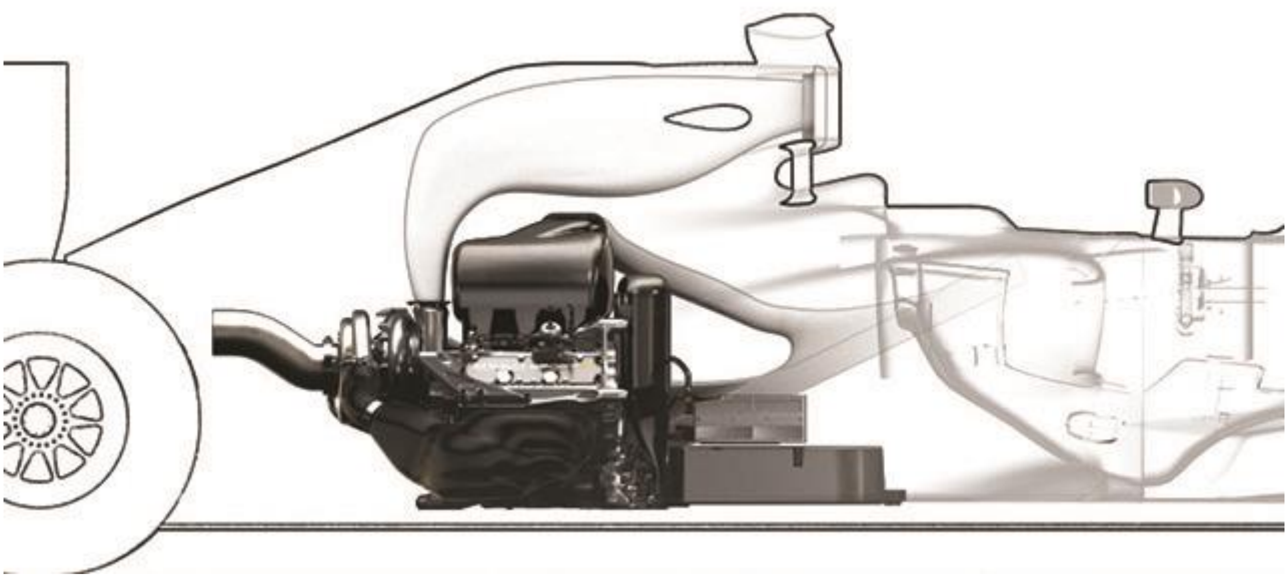
MGU-H
The MGU-H is connected to the turbocharger. Acting as a generator, it absorbs power from the turbine shaft to convert heat energy from the exhaust gases. The electrical energy can be either directed to the MGU-K or to the battery for storage for later use. The MGU-H is also used to control the speed of the turbocharger to match the air requirement of the engine (eg. to slow it down in place of a wastegate or to accelerate it to compensate for turbo lag.)

So it is both energy recovery and anti lag in one!
The MGU-H produces AC current, but the battery and MGU-K is DC current so a highly complex convertor is needed.

Very high rotational speeds are a challenge as the MGU-H is coupled to a turbocharger spinning at speeds of up to 100,000rpm. Bearing design and again cooling are critical.

Battery
Heat and Kinetic Energy recovered can be consumed immediately if required, or used to charge the Energy Store, or battery.

The stored energy can be used to propel the car with the MGU-K or to accelerate the turbocharger with the MGU-H. Compared to 2013 KERS, the ERS of the 2014 power unit will have twice the power (120 kW vs 60 kW) and the energy contributing to performance is ten times greater.



The battery has a minimum weight of 20kg to power a motor that produces 120kW. Each 1kg feeds 6kw (a huge power to weight ratio), which will produce large electromagnetic forces. The battery is mounted behind the driver and underneath the fuel cell.

The electromagnetic forces can impact the accuracy of sensors, which are particularly sensitive. Balancing the forces is like trying to carry a house of cards in a storm – a delicate and risky operation.

However a battery is not mandatory, indeed in 2013 one team used a system with both ultra capacitors and a battery to get a performance boost. In WEC where the same rules are in force, flywheel and capacitor storage is used. Both are legal in F1.

The strategy.
How teams will deploy the new power units on track, its not just a case of rev it up and go!

A standard lap
nder acceleration (eg. down the pit straight) the internal combustion engine will be using its reserve of fuel. The turbocharger will be rotating at maximum speed (100,000rpm). The MGU-H, acting as a generator, will recover energy from the exhaust and pass to the MGU-K (or the battery in case it needs recharging). The MGU-K, which is connected to the crankshaft of the ICE, will act as a motor and deliver additional power to pull harder or save fuel, dependent on the chosen strategy.

At the end of the straight the driver lifts off for braking for a corner. At this point the MGU-K converts to a generator and recovers energy dissipated in the braking event, which will be stored in the battery.

Under braking the rotational speed of the turbo drops due to the lack of energy in the exhaust which, on traditional engines, leads to the curse of the turbo engine – turbo lag. This phenomenon occurs when the driver re-accelerates: Fuel injection starts again and generates hot exhaust gases which speed up the turbo, but it needs time to return to full rotational speed where the engine produces 100% of its power. To prevent this lag, the MGU-H acts as a motor for a very short time to instantaneously accelerate the turbo to its optimal speed, offering the driver perfect drivability.

Over the course of the lap, this balance between energy harvesting, energy deployment and (carbon) fuel burn will be carefully monitored.

'The use of the two types of energy needs an intelligent management,' Technical Director for new generation Power Units, Naoki Tokunaga, explains. 'Electrical energy management will be just as important as fuel management. The energy management system ostensibly decides when and how much fuel to take out of the tank and when and how much energy to take out or put back in to the battery.

'The overall objective is to minimise the time going round a lap of the circuit for a given energy budget. Obviously, if you use less energy, you will have a slower lap time. That's fine. However, what is not fine is to be penalised more than the physics determines necessary. In the relationship between fuel used versus lap time, there is a borderline between what is physically possible and the impossible – we name it 'minimum lap-time frontier'.

'We always want to operate on that frontier and be as close to the impossible as we can. The strategy is subject its own limits, namely the capacity of the PU components and the Technical Regulations. The power output of the engine subject to its own limits, plus MGU-K power and the energy the battery can deliver to it are all restricted by the rules. It is a complex problem. The solution is therefore determined by mathematical modelling and optimisation – we call it 'power scheduling'.

'As a result, there will be a complex exchange of energy going on between the components in the system network, at varying levels of power over a lap. This is completely invisible to the driver as it is all controlled electronically by the control systems. The driver will be able to feel it but no driver intervention is normally required, so they can concentrate on the race in hand. Of course, there will be certain driver-operated modes to allow him to override the control system, for example to receive full power for overtaking. Using this mode will naturally depend on the race strategy. In theory you can deploy as many times as you want, but if you use more fuel or more electrical energy then you have to recover afterwards. The 'full boost' can be sustained for one to two laps but it cannot be maintained.'

The fact that the driver does not control the balance between fuel and energy does not lessen the involvement of the driver in any way, and in fact his job will be more complicated than in previous seasons. He will still be fighting the car to keep it under control during hard braking, managing braking to avoid understeer into a corner, applying delicate control over the throttle pedal mid-corner, sweeping through complex corners, throwing the car into high speed corners. In terms of driving style, there may well need to be some adjustments.

'The throttle response will be different so the driver will need to readjust for this,' Tokunaga explains. 'Effectively, once the driver applies full throttle, the control systems manage the power of PU, with the aim to minimise the time within the given energy.

However full throttle no longer means a demand for full engine power. It is an indication to the PU given by the driver to go as fast as possible with the given energy. He will still need to adjust for the different 'feel' of the car with the energy systems.'

Race strategy and race management will also be more flexible than in the past and the optimum solution will vary vastly from circuit to circuit, dependent on factors including percentage of wide open throttle, cornering speeds and the aerodynamic configuration of the car.

'In essence, engine manufacturers used to compete on reaching record levels of power, but now will compete in the intelligence of energy management,' Tokunaga surmises.

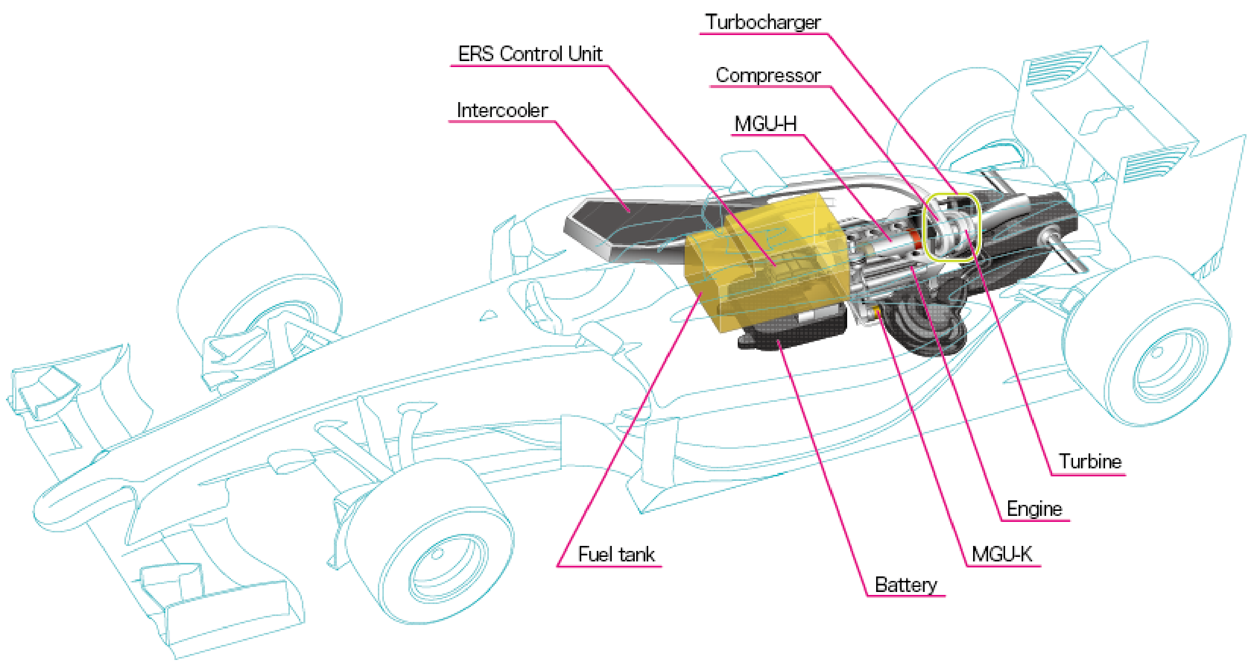
A hot lap

In 2014, the fastest car on a Saturday will still start on pole since the sessions will be run 'flat out'. The cars will still be limited by the fundamental fuel flow restriction of 100kg/h but the 100kg fuel limit will be irrelevant since very little fuel is burned over one lap. The driver will therefore be able to use 100% of the allowed fuel flow and the entire energy budget from the battery store for his qualifying lap. However, should he choose to use all the energy on one lap, he will not be able to complete two flat out timed laps and will instead have to wait until the store recharges. This will lead to some even tenser sessions and a number of different strategic calls.

3. The F1 Power Units and Energy Recovery Illustrated

3.1 POWER UNIT

The change in terms from "engine" to "power unit" signifies a shift in thinking, from developing engines for pure horsepower to the pursuit of energy-efficient power units, leading to the highest level of energy-efficiency through environmental technologies.
How do the two types of energy recovery systems, the kinetic energy recovery system and thermal energy recovery system, work?



* This diagram does not represent Honda's actual power unit.

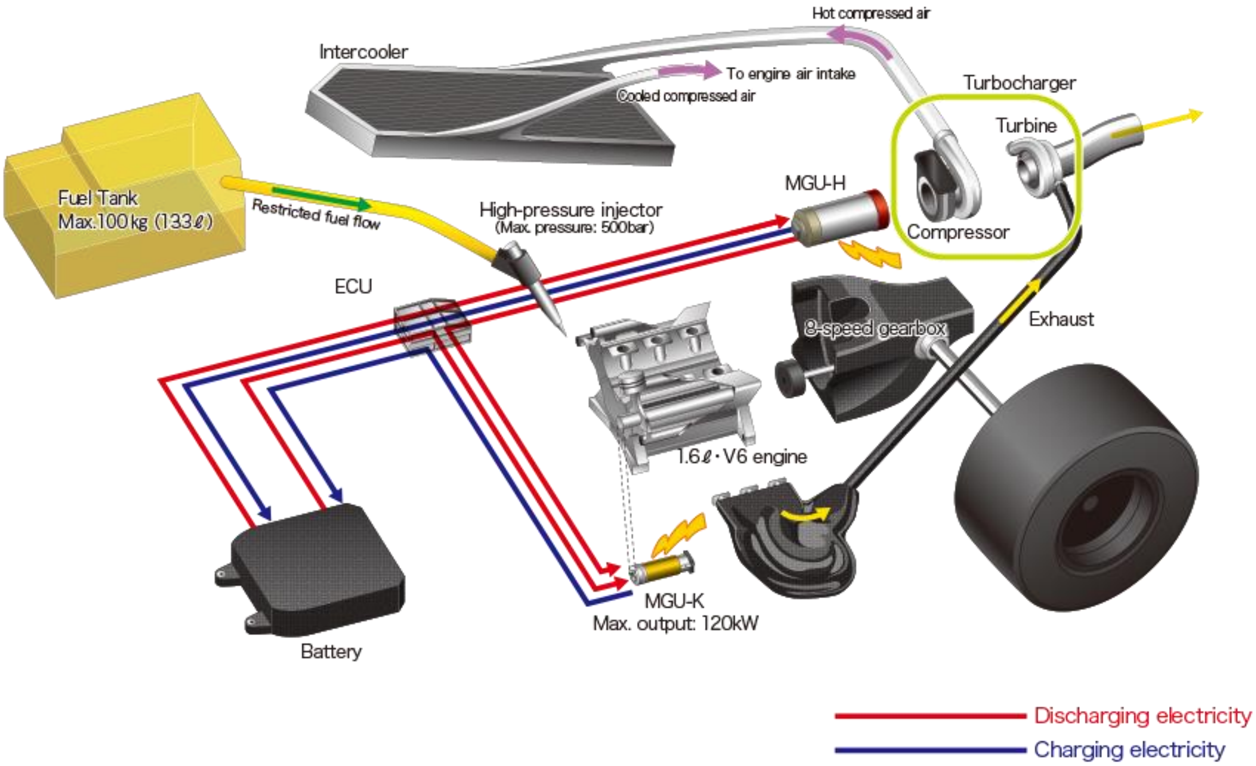
The kinetic energy recovery system is a evolution of on KERS (Kinetic Energy Recovery System), the system used in F1 racing from 2009 to 2013, and works similarly to the hybrid system for the Accord Hybrid and Fit Hybrid, by using a motor and electrical generator to convert kinetic energy into electrical energy.

With an engine-powered car, kinetic energy through braking is lost into as it becomes thermal energy through the brake units. In other words, energy is lost through braking. With a hybrid system, this lost energy is recovered by the motor/generator unit as electrical energy, and is stored in the battery, which can then be used to power the motor during acceleration. The kinetic energy recovery system's motor/generator unit is called "MGU-K" (Motor Generator Unit - Kinetic).

The second system, the thermal energy recovery system, captures the thermal energy generated from the engine's exhaust. Hot exhaust from the engine's combustion chamber is normally lost via the exhaust pipes. The thermal energy recovery system, a motor/generator unit, reuses this thermal energy to generate electricity. This unit is called “MGU-H” (Motor Generator Unit - Heat).

3.2 POWER UNIT CONFIGURATION

Power units for F1 machines are located behind the driver’s seat (cockpit), where the batteries are also located.



* This diagram does not represent Honda’s actual power unit.

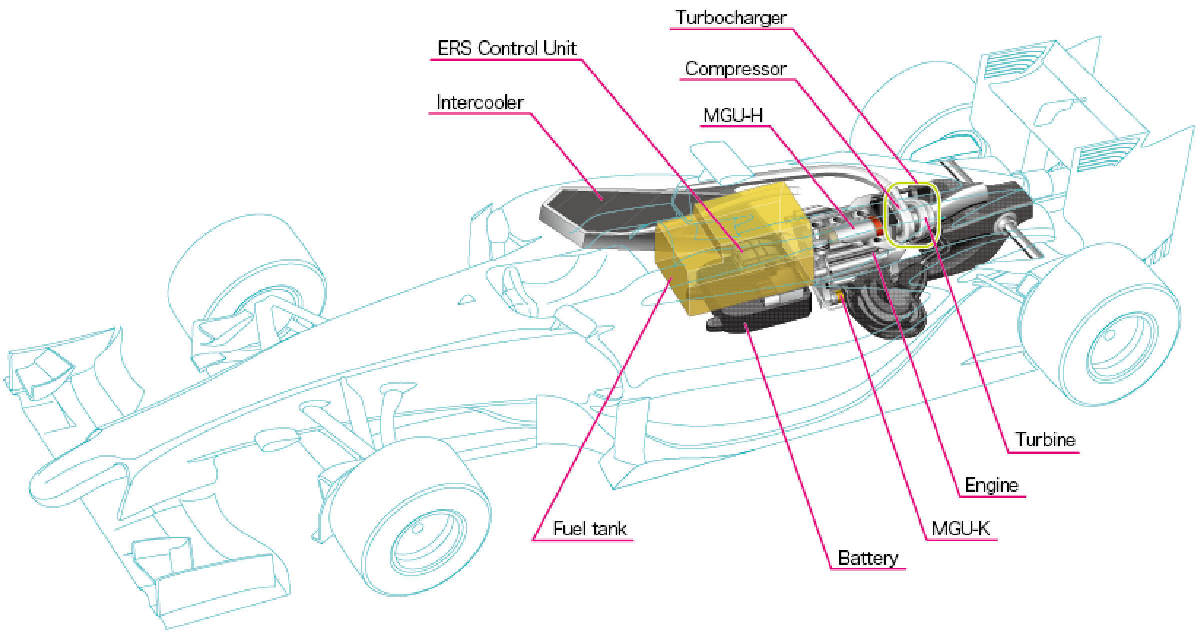
F1 regulations allow for one turbocharger with concise regulations for where it can be installed. The turbocharger increases the amount of air fed into the engine, which is cooled by the intercooler and fed into the engine’s intakes. The MGU-H has to be connected to the turbocharger.

The new 2014 regulations limit fuel usage to 100kg, and fuel flow to 100kg/h per race. Imagine Fuel usage as the capacity of the fuel tank, and fuel flow as the amount of fuel that flows from the fuel tank. Both the total amount of fuel, and the maximum amount of fuel flowing at any time, are limited per race. These regulations allow teams to use 30% less fuel compared to 2013 regulations. Due to fuel flow restrictions, it is harder to produce engine power, yet the smaller fuel tank capacities demand higher fuel efficiency.

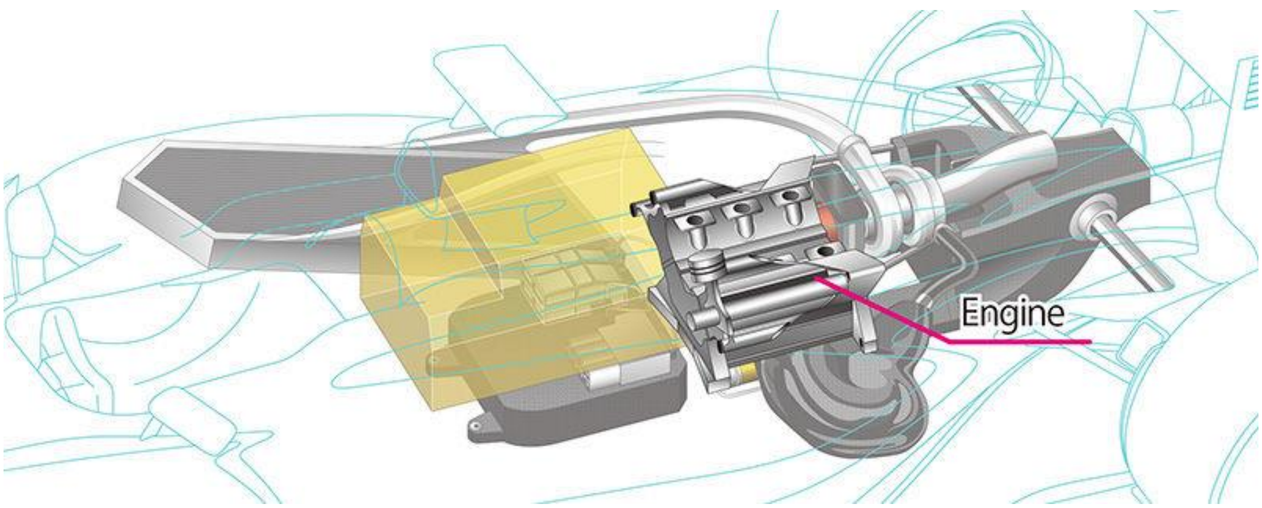
F1 machines need to use the limited fuel carefully to be able to finish a race. Races cannot be won by driving slow, so the thin trickle of fuel needs to be efficiently converted into power. To win in F1 racing, the engine needs to be fuel efficient and powerful, and the two energy recovery systems need to be utilized wisely.

Every drop of gasoline must produce maximum power, and the machines must have absolute speed that is expected of an F1 Racing. These technologies from developing F1 power units will be valuable for production cars of the future.

3.3 POWER UNIT COMPONENTS



3.3.1 Engine



The 2013 2.4-liter normally-aspirated V8 engine was replaced under the new 2014 regulations with a 1.6-liter V6 turbo engine with direct fuel injection. The engine is one-third smaller, and there are two-less cylinders, following the global trend of downsizing.

With a smaller capacity and less cylinders, the engine alone cannot be as powerful as before. Forced induction devices, such as turbochargers, allow the engine to be more compact, and produce the same power as before. The aim of engine downsizing is to reduce the size of the engine and increase fuel efficiency while producing the same power as a larger, normally-aspirated engine. Turbocharged engines can be built smaller, with a higher fuel efficiency.

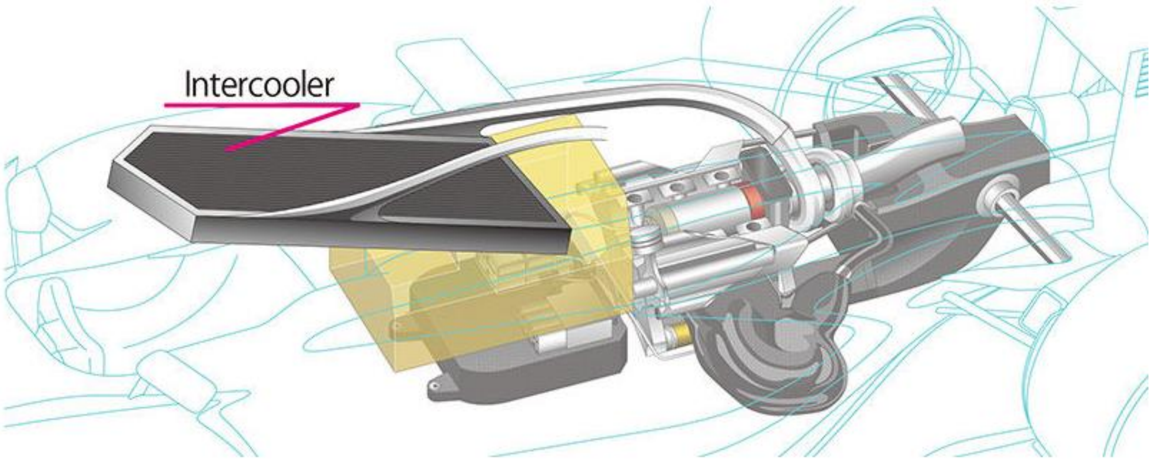
Until 2013 F1 engines were limited to 18,000 rpm, but from 2014, the rev limit is reduced to 15,000 rpm, with the maximum fuel flow capped at 10,500 rpm.

Output increases proportionately with the amount of fuel burned, so higher revs burn more fuel, and increase output, in a shorter time. By capping the maximum fuel flow at 10,500 rpm, only the same amount of fuel flow is available at higher revs, increasing mechanical resistance, and decreasing the merits of revving higher.

F1 engines of the past were designed to maintain higher revs to create higher output, but the new restrictions shift the focus to designing engines that use energy more efficiently.

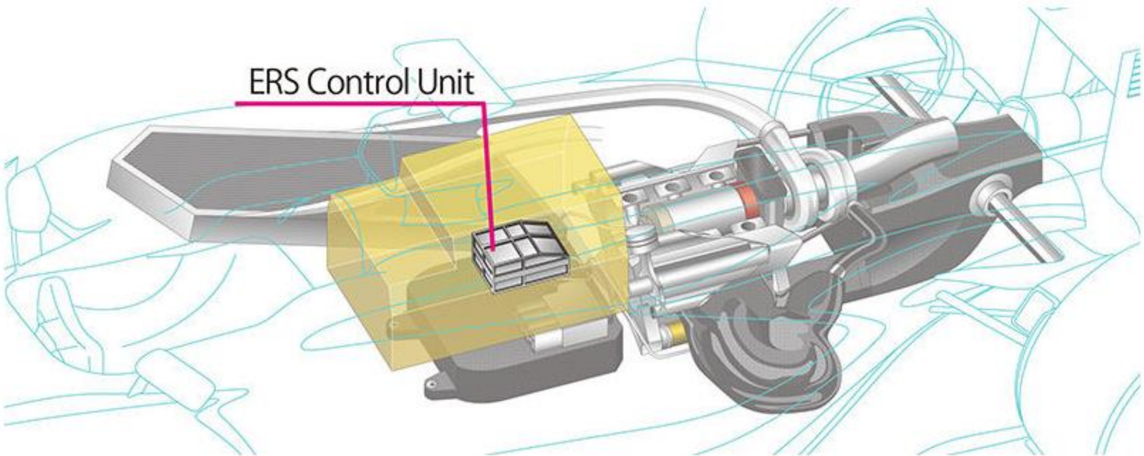
	2013	**2014**
Engine type	V8	V6
Capacity	2.4L	1.6L
Aspiration	Natural	Turbo
Fuel injection	Port injection	Direct injection
Maximum injection pressure	100bar	500bar
Maximum engine revs	18,000rpm	15,000rpm
Weight	95kg (Engine)	145kg (Power Unit)
Maximum fuel limit	None	100kg
Maximum fuel flow	None	100kg/h
Maximum engines (per driver per season)	8	5 (4 engines from 2015)

3.3.2 Intercooler



The intercooler reduces induction air heat created by the turbocharger. Hot air into the combustion chamber can cause abnormal combustion, lowering the engine's performance. The intercooler lowers the intake air to a temperature suitable for combustion.

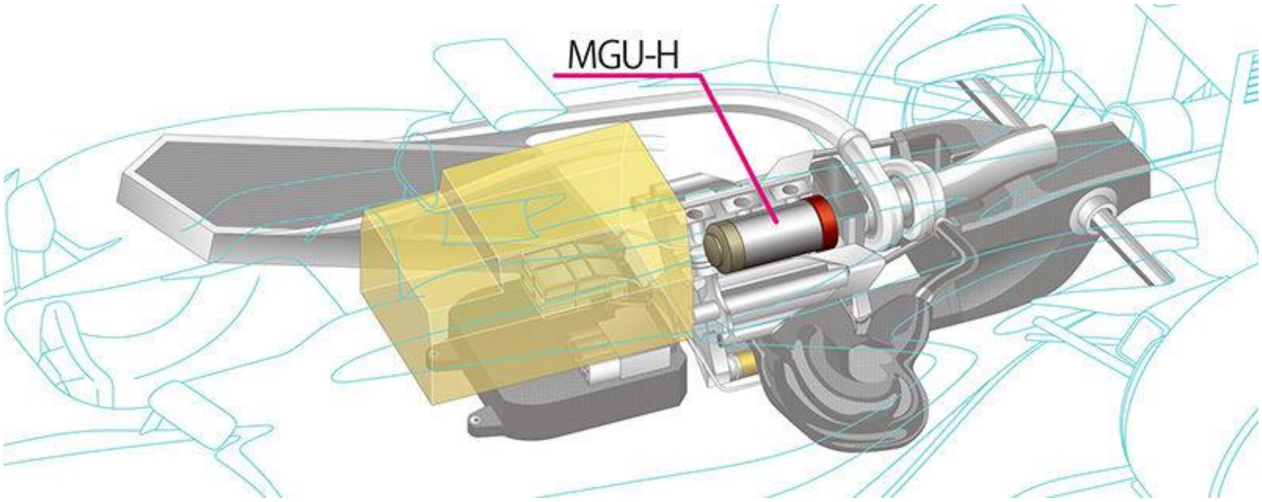
3.3.3 ERS Control Unit



The ERS (Energy Recovery System) control unit is a computer that controls how energy in the power unit is used. It is the brains of the power unit, and its software determines how well the engine and two MGUs perform under constantly and rapidly changing environment and driving conditions.

The battery operates using direct current (DC), as opposed to the MGU-K and MGU-H which operate using alternating current (AC). The ERS control unit includes AC/DC and DC/AC converters to convert electricity between the battery and MGU-K / MGU-H. Technologies developed for conversion efficiency and heat management will undoubtedly find their way to production hybrid cars.

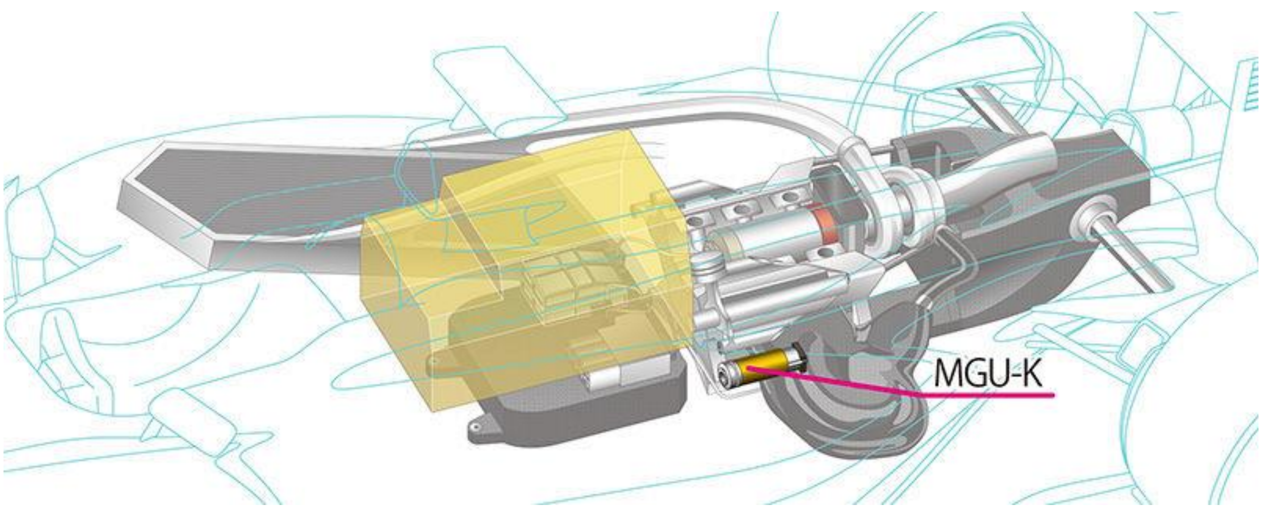
3.3.4 MGU-H



The MGU-H converts heat energy from exhaust gases into electrical energy, and is yet to be used in conventional hybrid cars. MGU-H technologies developed in F1 racing may find their way to production cars in the future.

Unlike the MGU-K, F1 regulations do not place energy usage restrictions on the MGU-H. Based on thermal energy from the turbocharger. Electricity generated by the MGU-H may be fed directly into the MGU-K, effectively bypassing the MGU-K restrictions and tapping the full 160PS, highlighting the importance of developing a system to fully utilize the MGU-H. The new F1 power unit heavily depends on how effectively the MGU-H performs.

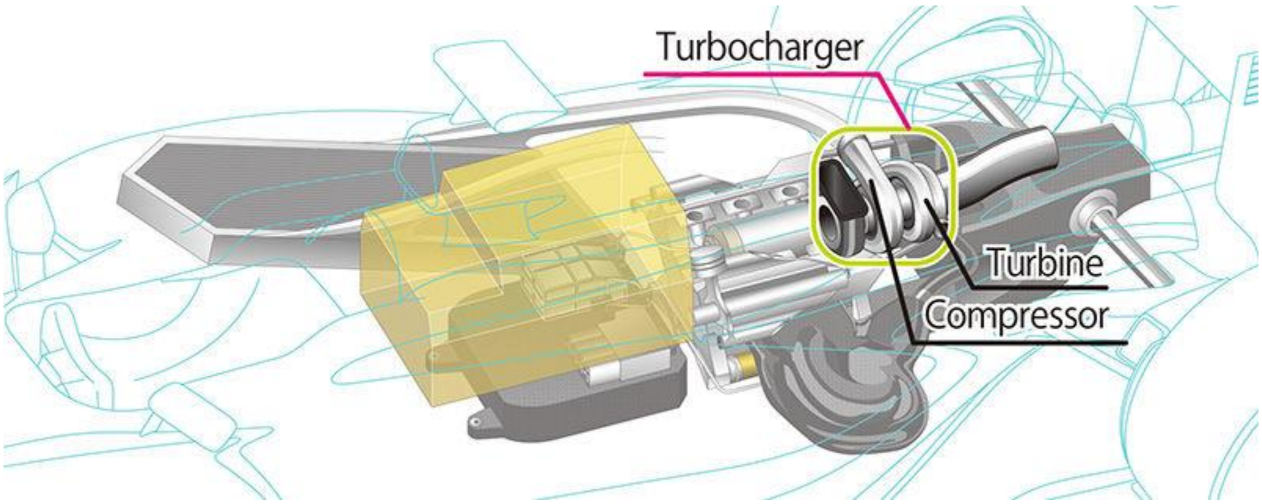
3.3.5 MGU-K



The MGU-K converts deceleration kinetic energy into electrical energy, functioning similarly to motor/generator units in conventional hybrid cars. Maximum revs are limited to 50,000 rpm, and output to 120kW (approximately 160PS). When powering the F1 machine by using electrical energy stored in the battery, the MGU-K adds 160PS to the engine’s 600PS. The MGU-K alone produces more power than the Fit Hybrid’s combined engine and motor output of 103kW (139.5PS).

The electrical energy charging the battery from the MGU-K is limited to 2MJ (megajoules) per lap, and the maximum energy used by the battery to power the MGU-K is limited to 4MJ per lap.

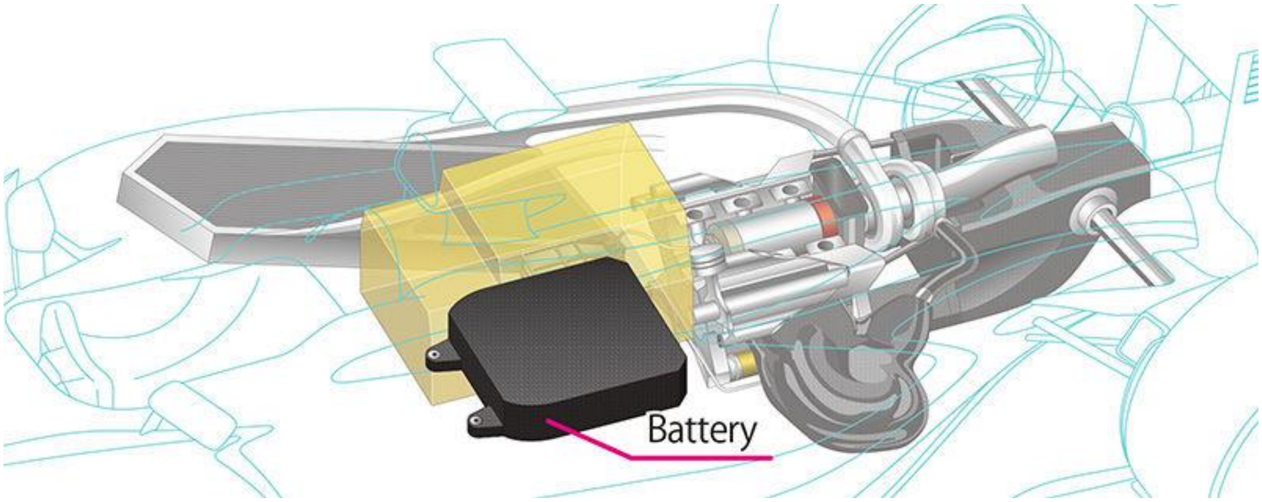
3.3.6 Turbocharger



The 2014 F1 regulations re-introduced turbocharged engines, a form of forced induction, to increase thermal efficiency. Turbochargers were allowed in F1 racing in the 1980’s, and in 1988, Honda’s turbocharged engines won 15 out of 16 grands prix. Turbocharged engines were banned the following year, in 1989, but after 25 years it has been re-introduced.

The turbocharger, a device to efficiently utilize the engine’s exhaust energy, comprises of a turbine and compressor supported by bearings on the same axis. Exhaust gas energy turns the turbine powering the compressor, which in turn compresses and increases air fed into the engine’s combustion chamber, thus allowing for more combustion and higher output. Conventional turbocharged V6 engines are generally equipped with two turbochargers, but F1 regulations limit the engine to one turbocharger, requiring power to be found by other means.

3.3.7 Battery



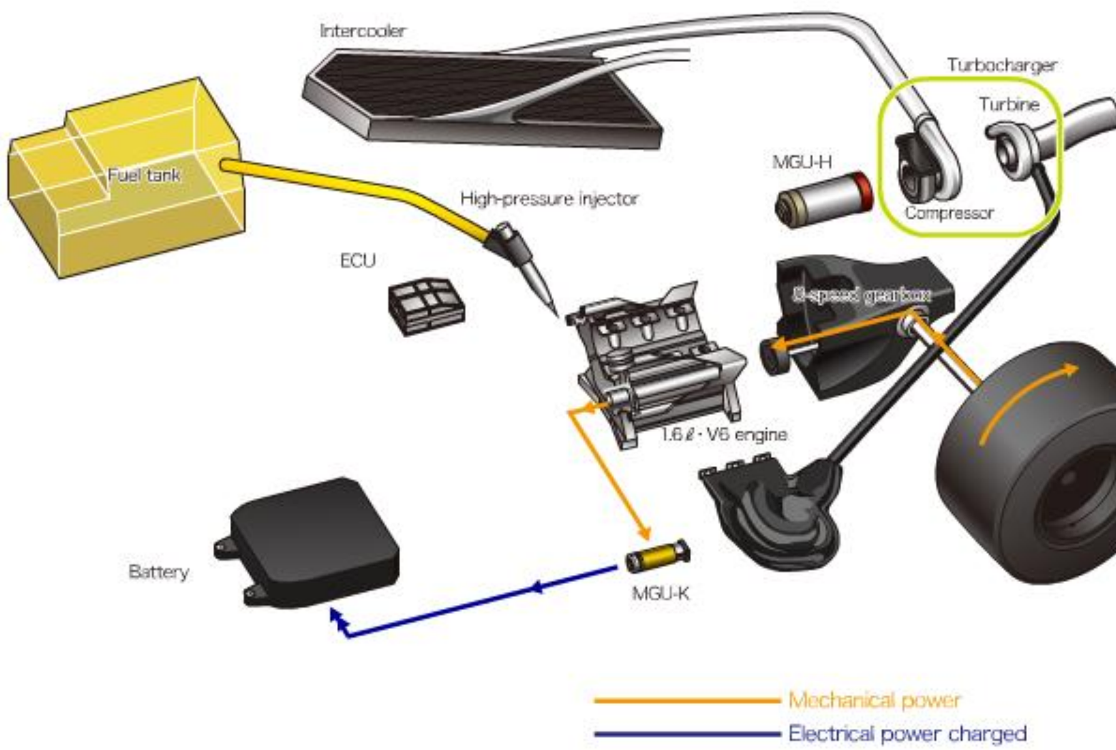
Energy storage devices (batteries) are used to store energy that would otherwise be lost. Regulations limit battery size to between 20 and 25kg, to avoid excessive development costs. Battery development and control technologies gained through F1 development will also be beneficial to production hybrid cars in the future.

3.4 ENERGY FLOW

How does energy flow within the power unit? Depending on what the F1 machine is doing on the track, energy is recovered, or is used to assist the engine.
**All energy flows through the ECU, but is not depicted for simplicity.*

3.4.1 Braking

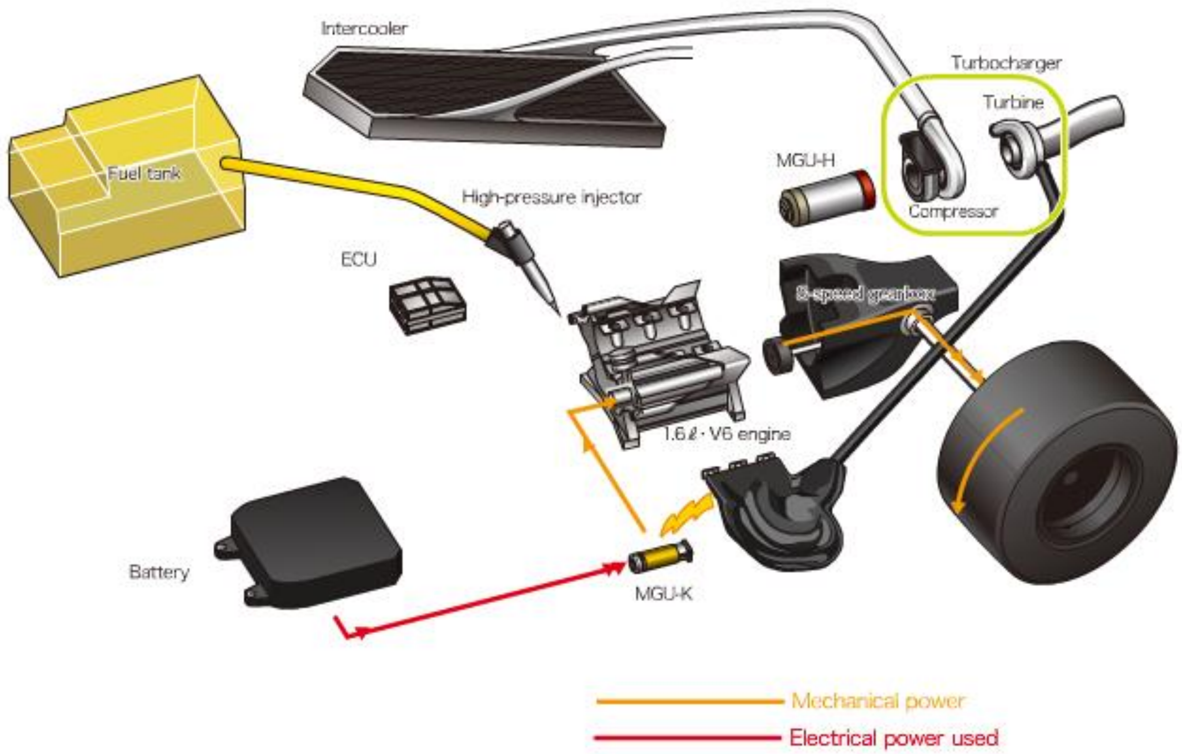
The energy flow is similar to a conventional hybrid car: The MGU-K recovers (or generates electricity from) part of the kinetic energy lost when the F1 machine is braking, and stores the electricity in the battery. The MGU-K's maximum output is 120kW and the amount of energy allowed to be stored is 2MJ per lap, so the F1 machine needs to brake for around 16.7 seconds per lap to reach this maximum charge.



* This diagram does not represent Honda's actual power unit.

3.4.2 Accelerating out of Corners (with MGU-K Power-assistance)

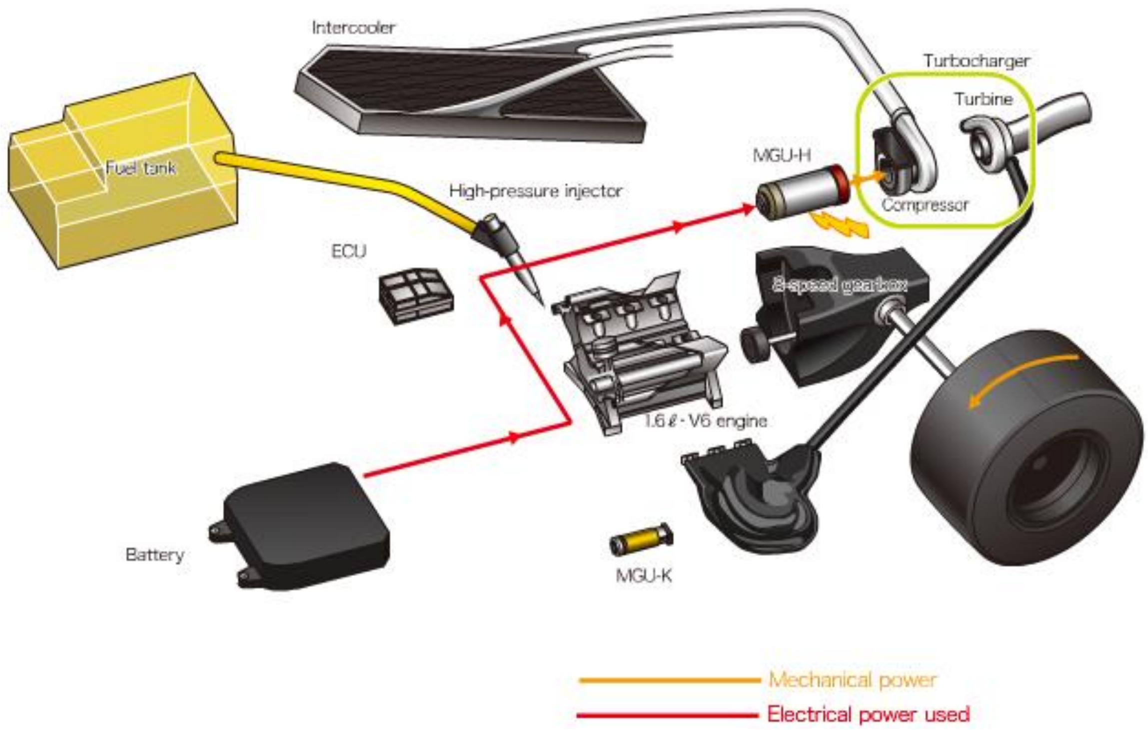
The F1 machine can accelerate faster out of corners by adding the output of the MGU-K to the engine's output.



* This diagram does not represent Honda's actual power unit.

3.4.3 Accelerating out of Corners (Solving Turbo Lag)

With turbocharged cars, when depressing the accelerator pedal after deceleration, the flow of exhaust gas increases, delaying the turbine to perform and hence the accelation requires additional time. This small time-lag is called "Turbo Lag." The MGU-H solves this problem by using a motor to power the compressor, without needing the turbine to wait for the exhaust gas.



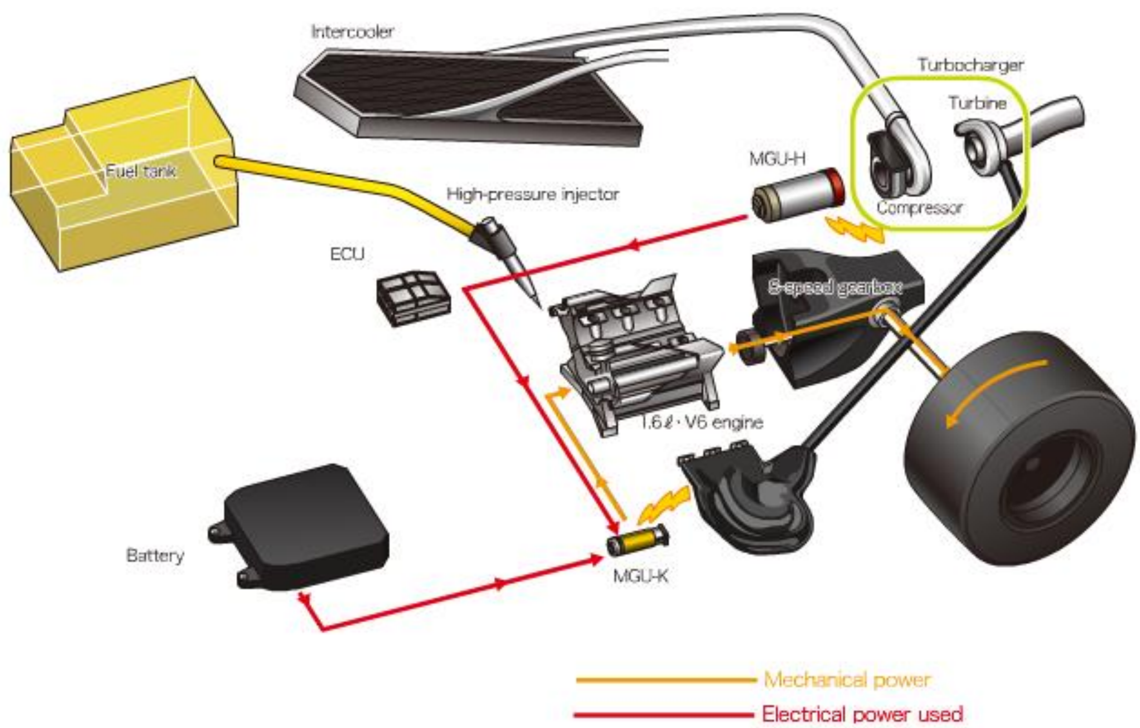
* This diagram does not represent Honda's actual power unit.

3.4.4 Full-acceleration (with MGU-K and MGU-H Power-assistance)

The turbocharger uses its compressor to send compressed air into the engine. Under full-acceleration, the exhaust energy fed to the turbine can increase to a point where it exceeds the amount of air the compressor can handle to feed the engine.

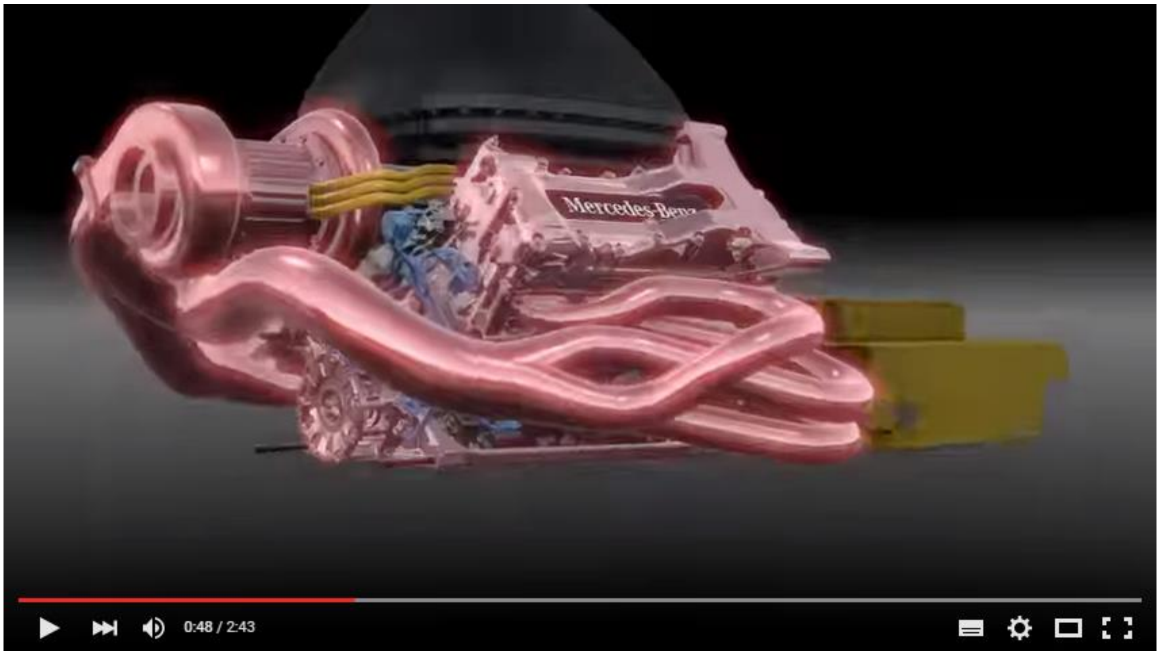
The MGU-H converts the excess exhaust energy into electricity, which it then sends to the MGU-K. There are no rules on how much electricity the MGU-H is allowed to generate, so the MGU-K's output can be added to the engine's output without worrying about the rules on the amount of electricity that the battery can charge or discharge. Unused exhaust energy can be efficiently used to accelerate faster.

Under full-acceleration out of corners, the battery can also send electricity to the MGU-K. This way, full-acceleration can be achieved at the maximum output allowed for the MGU-K, at 120kW.

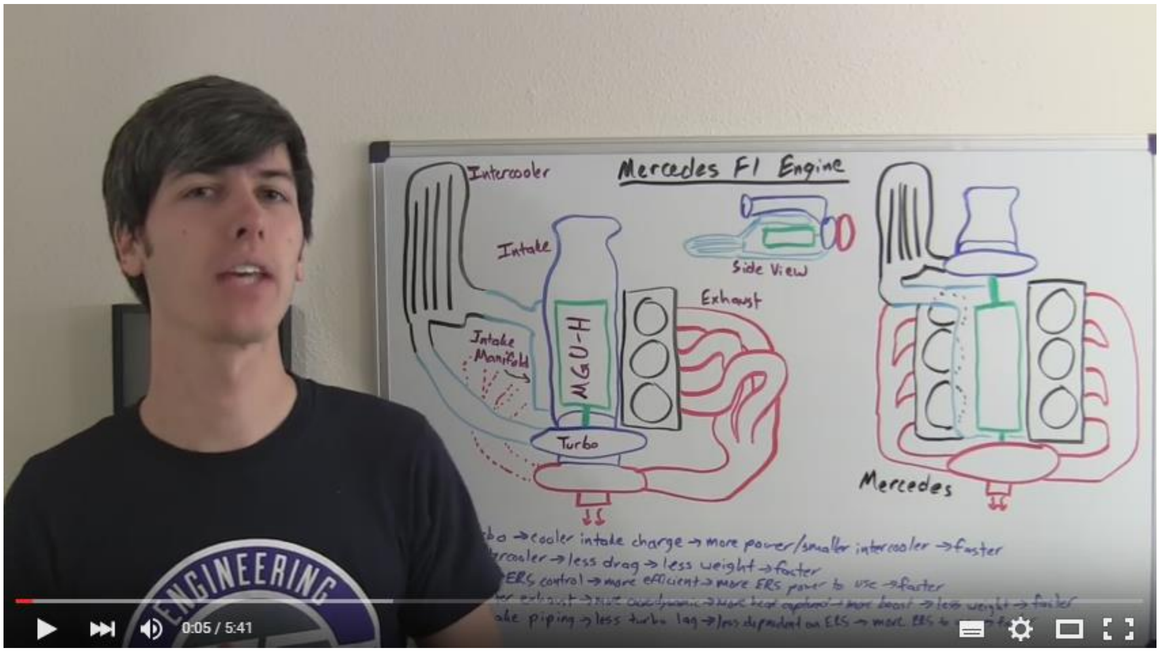


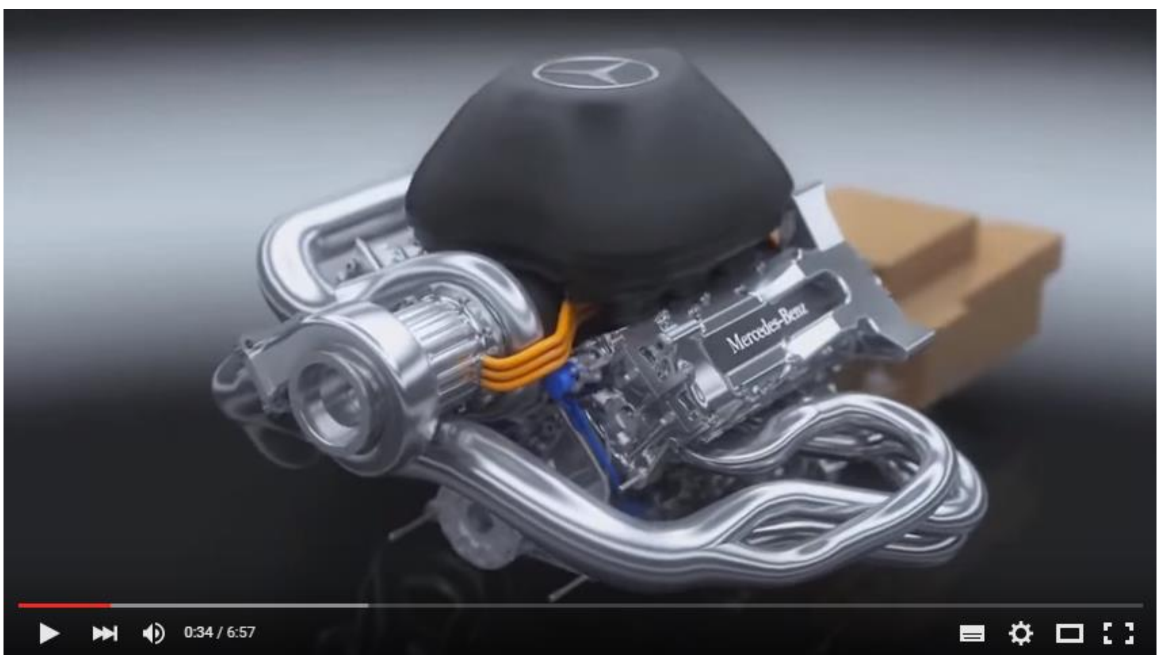
* This diagram does not represent Honda's actual power unit.

4. Video - 2014 F1 Mercedes Hybrid turbo V6 Power Unit explained



5. Videos - How Mercedes Dominated 2014-2015?

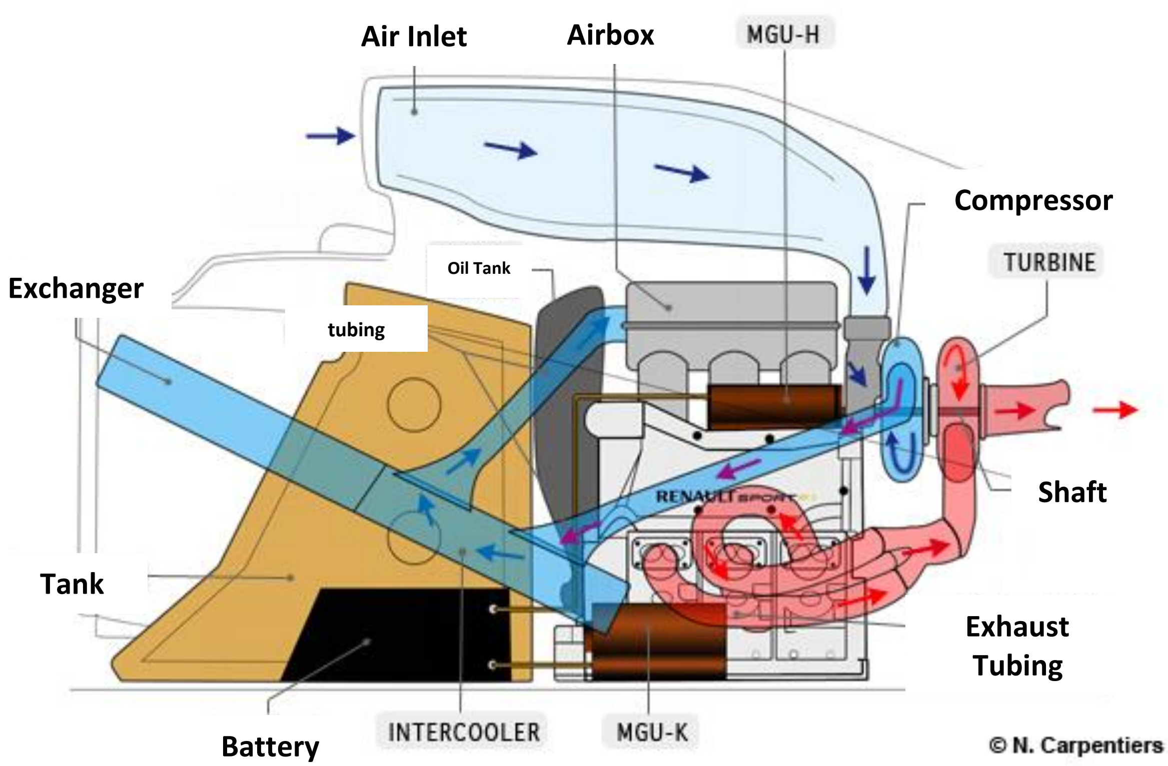




6. The Integration of the Power Units 2014

[Source: http://www.f1i.com – Nicolas Carpentiers]

6.1 The Integration of the Power Unit Renault 2014



Classic installation

On V6, Renault remained faithful to classical architecture: the compressor is stuck to the turbine. Schematically, a turbo consists of three parts: a turbine, compressor, and a shaft connecting them. The turbine, placed in the gas flow escaping from the engine is driven at high speed. It is connected by a shaft to a compressor located upstream of the block of the inlet duct. This compressor sucks and compresses the ambient air to be cooled before being sent into the cylinders.

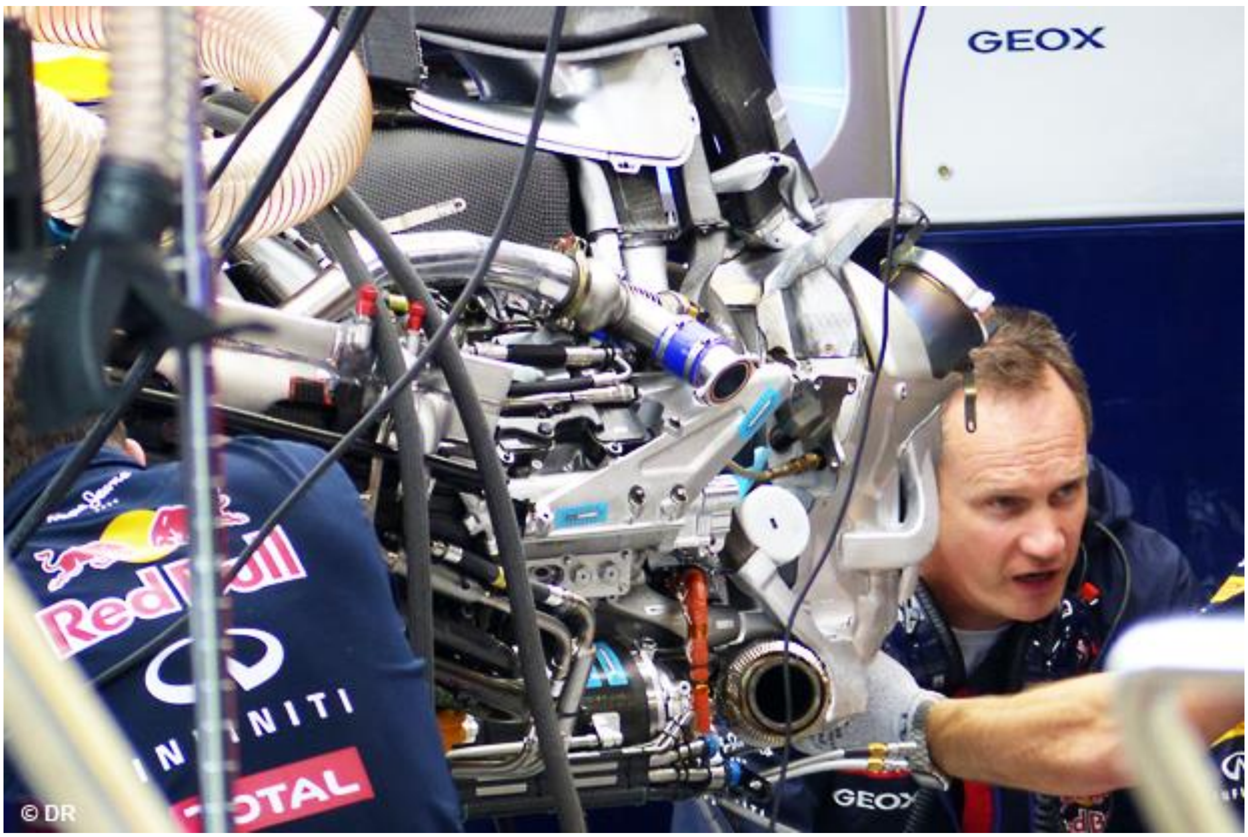
As seen in the first diagram, the turbocharger developed by Renault forms a compact assembly, located at the rear of the engine. The axis connecting the compressor to the turbine is very short.

The MGU-H - which recovers the energy coming from the rotation of the shaft - installed inside the "V" formed by the two rows of cylinders. The advantage of such a configuration? Install the

V6 very near the gas tank to get a good weight distribution (see the position of the exchanger, the Mercedes V6 would be a little less close).

In contrast, with respect to implantation that have selected the Germans, this arrangement involves longer ducts.

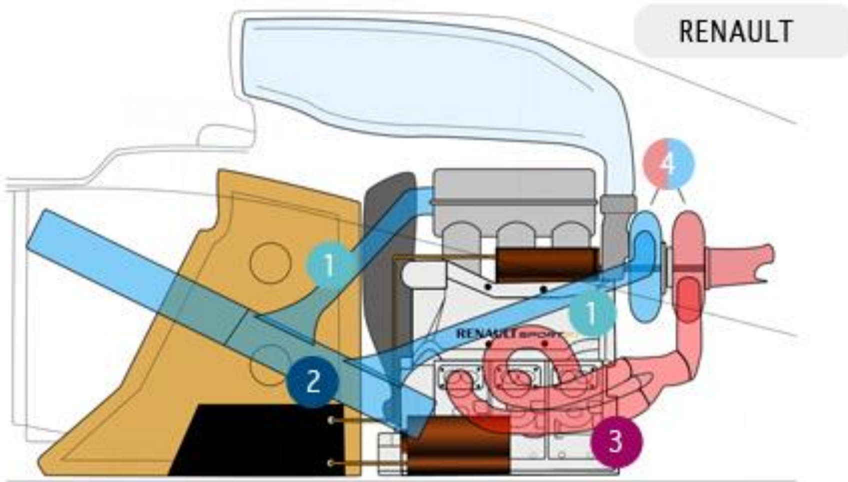
First, because the air coming through the air box takes a while to reach the compressor, since it is on the back. Difficulty amplified by the fact that the compressor air inlet is not perfectly aligned.

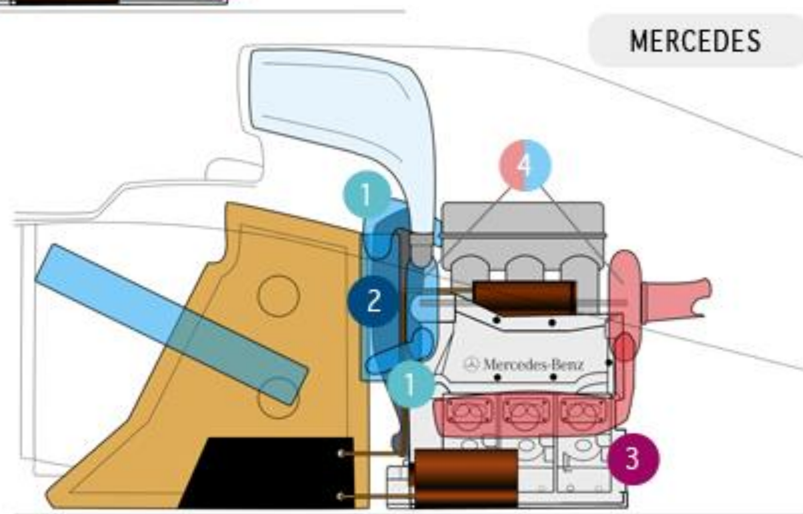


Ducts Length and response time

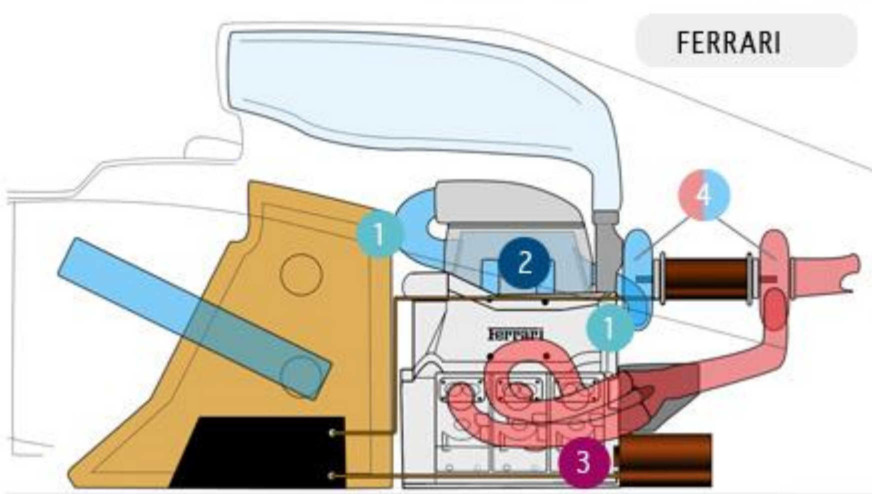
Secondly, because the air path to reach the exchanger is longer than on the PU106A as installed in the Mercedes W05, as explained in our analysis of the German V6. Therefore, on the Renault, you need more power to circulate the air (that said, this distance is just as great on the Ferrari engine):
"The issue of transitional must indeed be asked, agrees Taffin. This is turbocharged engines, with response time. The pipes here [pointing Renault schema] are longer than there [Mercedes]. "

The heat exchanger that cools the compressed air, should not be confused with conventional water and oil coolers. On all powered cars the French manufacturer, the exchanger and other heaters are placed side by side, inside the side pods. This has an impact on the internal aerodynamics of the car: welcoming two types of radiator, the flanks of the Red Bull and Lotus are more congested than the Mercedes W05 or those of the Ferrari F14 T. On the last , the exchanger is remote from other radiators in order to clear the side pods as possible and thereby reduce the blockage of airflow.





1 – Air path
2 – Intercooler
3 – Piping
4 – Proximity Compressor/Turbine

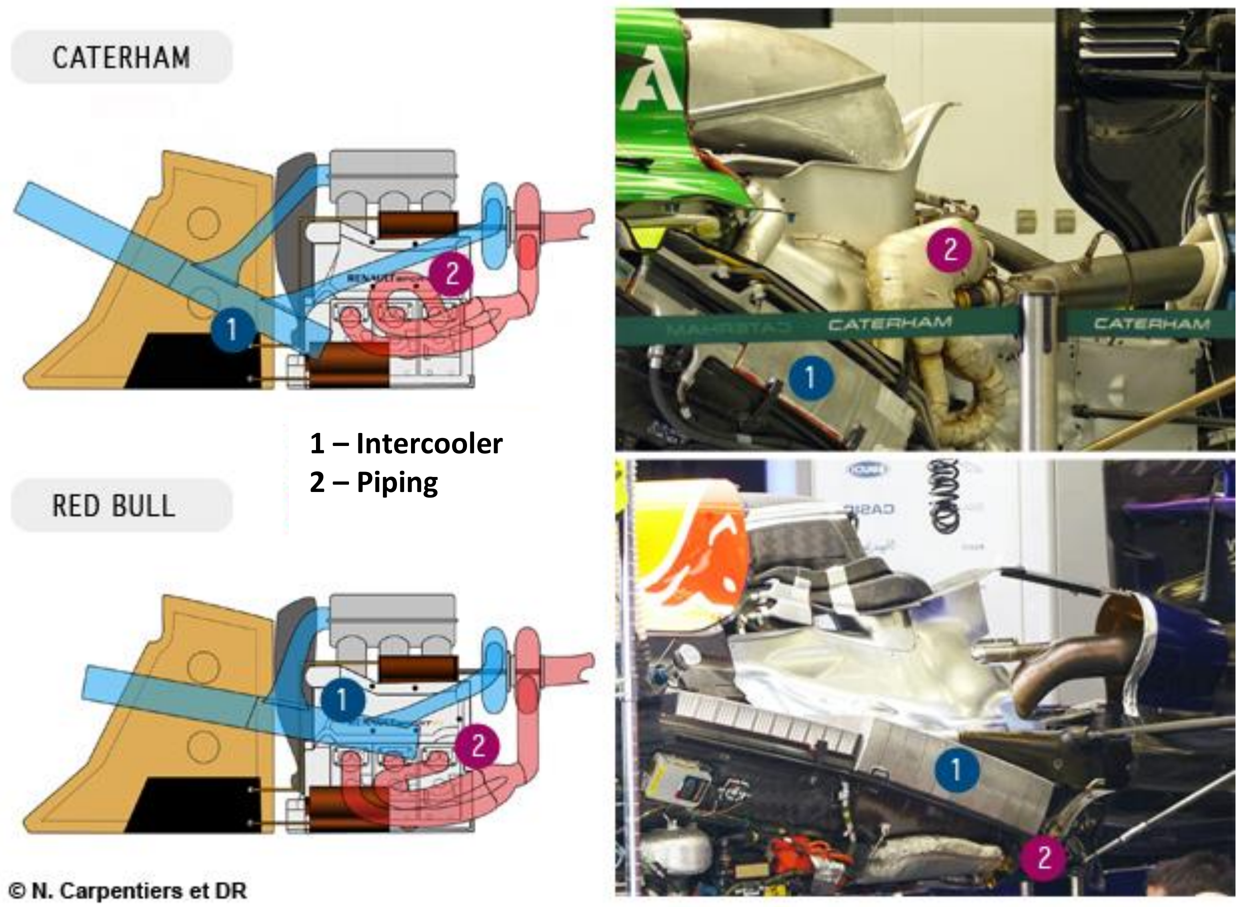


Thermal conflict

Moreover, in the Renault configuration, the compressor, because it is attached to the turbine, is in a very hot area: 1000°C. However an engine does not like air above 50°C. It is therefore necessary to further cooling the air than on the Mercedes engine (compressor and turbine which are widely spaced) by means of an imposing exchanger, which penalizes aerodynamics.

Another bias, shared with the Italian V6: Renault retained the classic exhaust pipes coming from the engine and head to the turbine. Where Mercedes truncated them to integrate them into a very short single collector ("log manifold" in English).

In other words - and cheerfully forcing the line - instead of sacrificing power of the ICE as did the engineers of Brixworth, the engineers of Viry-Chatillon have privileged optimization of thermal exhaust V6 , to the detriment of the compactness and to the amount of energy supplied to the turbine and then recovered by the MGU-H.



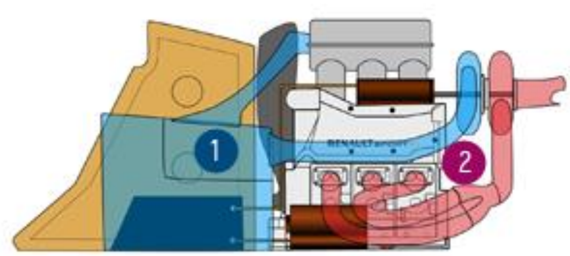
Powered by the same engine in 2014, Red Bull, Lotus, Toro Rosso and Caterham does not however include the French V6 in the same way.

While Caterham (and probably Toro Rosso) headed up the exhaust pipes - therefore cover the block (like on the cars powered by Ferrari) - Red Bull has made the opposite choice. To install its radiators as horizontal as possible (and thus limit the air resistance), Adrian Newey has housed the tubing in the heat exchanger, pinning them against the floor. During winter testing, the team had met a lot of overheating problems in this area of the car.

In the images, we note the significant size of the exchanger, divided into two parts, one in each side pod: good symmetry between the left and right side pods of the car is paramount. A differential in the drag or the aero performance between the two flanks substantially alter the car's behavior. This configuration of exhausts also allows Red Bull to back the exchanger in order to reduce the length of the air path to the exchanger (particularly short on the Mercedes V6).

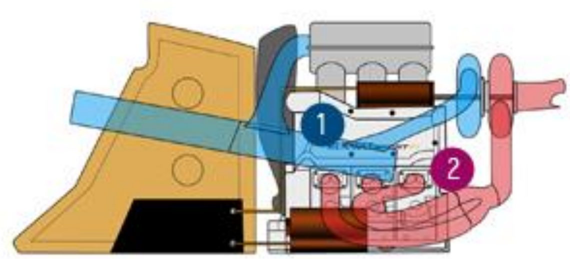
For its part, Lotus (see below) installed its radiator vertically, always to reduce the length of the cooling ducts. In contrast, Enstone seems to use an air / water heat exchanger, like Mercedes, certainly heavier but more compact solution than air / air as implemented on the Red Bull. The layout of the pipes of the E23, positioned low, is halfway between that of Caterham and the more radical Red Bull.

LOTUS



1 – Intercooler
2 – Piping

RED BULL



© N. Carpentiers et DR

The architecture does not determine alone the competitiveness of an engine. Let us remember, the difference there may be between theory and practice: a drawing, as clever as it is, must be fully implemented - including the electronic level - to bring the expected benefits. Thus the same choice of architecture can successes or failures: Mercedes and Ferrari have decided to place the heat exchanger in the center of the chassis, in order to clear the decks and optimize the internal aerodynamics. In one case, the solution works, the other not ...

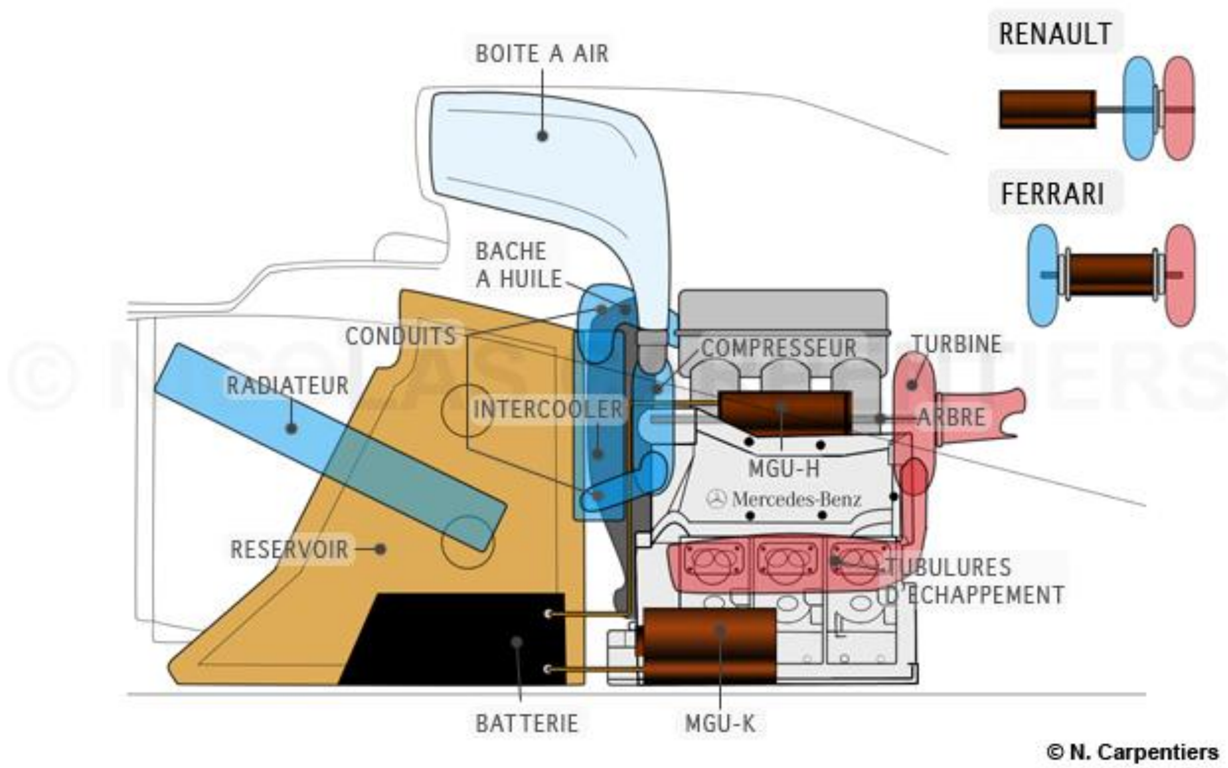
This is especially the delay in the launch of the hybrid V6 program that the French manufacturer pays today. That said, to prepare the specification for the next season, Renault has admitted to analyse all possible configurations including the one adopted by Mercedes, which we will examine later:
"Both solutions are studied in parallel, for now it has not been chosen concludes Taffin. This is a fairly significant change, current tests on the bench are conducted in this configuration [the current architecture] because we have many other things to try, it's not our primary layout. But it is not impossible that a version like that [Mercedes] see the light of day next year or the year after".

The Losange likely retain its architecture, but will receive the support of Red Bull in certain areas (eg, energy recovery). The team has put in place a team of engineers at Milton Keynes it recruited itself, which is an "extension" of Renault Sport, in the words of Cyril Abitboul.

(*) The patterns presented here are simplified compare to the complex reality of powertrains (the tank is normally dug to accommodate the oil tank; drawing exhaust and air intake are

schematic; many devices are missing, etc.). Thank you to Rémi Taffin from Renault Sport to have lent to the delicate exercise of comment, given his reserve duty.

6.2 THE INTEGRATION OF THE POWER UNIT MERCEDES 2014



Innovative installation

To meet the challenge of energy efficiency, engine manufacturers involved in this season's Grand Prix - Renault, Ferrari and Mercedes - have each taken different routes. We will closely examine the specifics of the Mercedes engine, the benchmark this season in terms of powertrain.

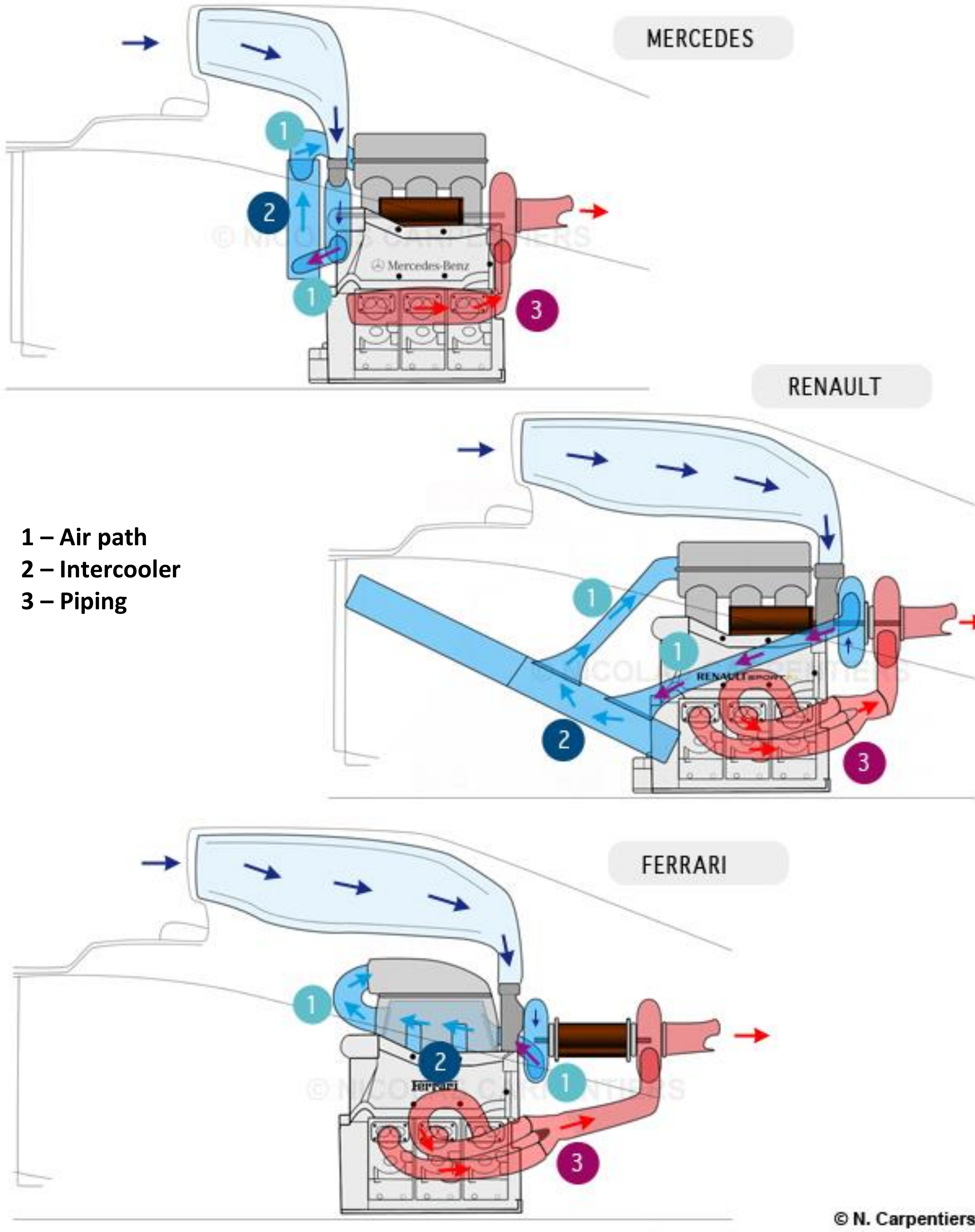
Compared to Renault, Mercedes has chosen an original implantation, which "breaks" the turbo. Schematically, a turbocharger is based on three elements: a turbine, a compressor and an axis that connects them. Renault and Ferrari choose to "glu" the compressor to the turbine. Mercedes completely separates the compressor of the turbine, as seen in the diagram above.

In other words, the turbine is mounted at the rear of the engine, while the compressor is placed in the front, on the other side of the block (can be located in the red cap on the picture below - showing the Mercedes engine in the McLaren garage). The two elements away from each other more than in a conventional architecture, are connected by an axle - therefore much longer - that pass inside the "V".

Triple asset

This unusal architecture has three advantages. The first is a better management of cooling, since the aluminum compressor and the pipes are mounted on the front of V6, far from the 900°C of the turbine and the hot exhaust pipes. Located in a less hot area than on the Renault, Mercedes compressor can use a smaller exchanger (because compressed air has less need to be cooled).

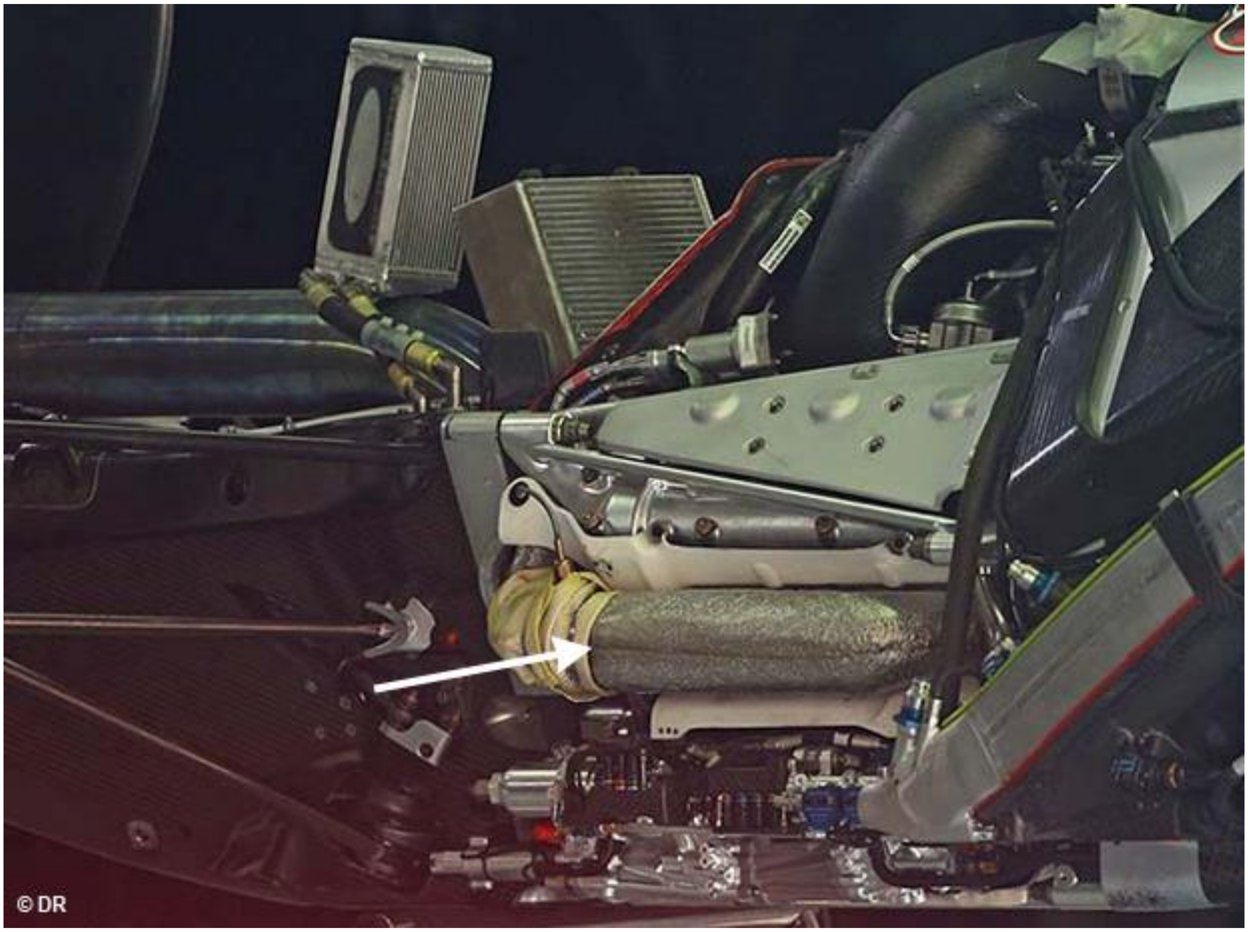
This is where the second asset of the engine fitted to the Silver Arrows. While Red Bull uses two imposing exchangers installed on each side of the engine in the side pods, the Brackley chassis engineers worked hand in hand with their engine colleagues of Brixworth to develop a single exchanger, housed in the monocoque itself roughly behind the pilot's head. On the Mercedes W05, the exchanger is installed in the chassis, in order to clear as much as possible within the side pods and thereby reduce the blockage of airflow (the side pods are also clean on the Ferrari F14-T because the heat exchanger is located in the center of the "V" formed by the two rows of cylinders). To recall, the heat exchanger cools the air compressed by air (Red Bull) or water (Mercedes, Ferrari, Lotus), whereas conventional water heaters and oil, housed in the side pods cool the V6, the transmission, etc.


MERCEDES
RENAULT
FERRARI
1 – Air path
2 – Intercooler
3 – Piping
© N. Carpentiers

Better energy expend

The third benefit is notable. As seen above, on the PU106A, the pipes which connect the compressor to the heat exchanger are considerably shorter than the engines designed by Renault and Ferrari, which reduces the famous turbo "response time". And reducing this gap reduces the proportion of energy recovered by the ERS that the MGU-H shall devote to the relaunch of the turbine when the accelerator pedal is not depressed. In other words, Mercedes lost less energy than competitors to maintain optimum rotational speed of the turbine and would therefore be able to focus more on the "boost" itself - appreciable gain when we remember that the regulation allows spending 4 MJ per lap but to recover only 2 MJ per lap. Able to fulfill the batteries faster than the Renault and the Ferrari, the Mercedes powertrain can spend the maximum power allowed by the regulations at every lap (and consume less fuel), which does not seem to be the case with other engine according to statements of a team owner to our colleagues from Auto Hebdo: "with the Mercedes engine, there is the confidence you get two laps in a row at full load. With others, it is 75% for a single lap. "

Besides the position of the exchanger in the chassis (which is specific to the W05: the radiator is placed conventionally in Williams, Force India and McLaren), the long expertise of Brixworth engine manufacturers in terms of energy recovery explained the effectiveness of the ERS on the Silver Arrow, more than the size of the compressor, as some observers have suggested. Contrary to most of the engine manufacturers, which at the time of the first KERS had left the teams to develop their own energy recovery systems and/or relied on the expertise of their suppliers (Magnetti Marelli for Ferrari and Renault), Mercedes, meanwhile, has continued to refine its home system. In 2010, when the teams agreed not to use KERS this year, Mercedes still continued to work on his system. If the second generation of KERS was much more effective than the previous one, its restriction by regulation (60 kW for 6.5 seconds against 33 seconds for 120 kilowatts today) has masked the progress in an area much determinant today in the overall performance of the car.



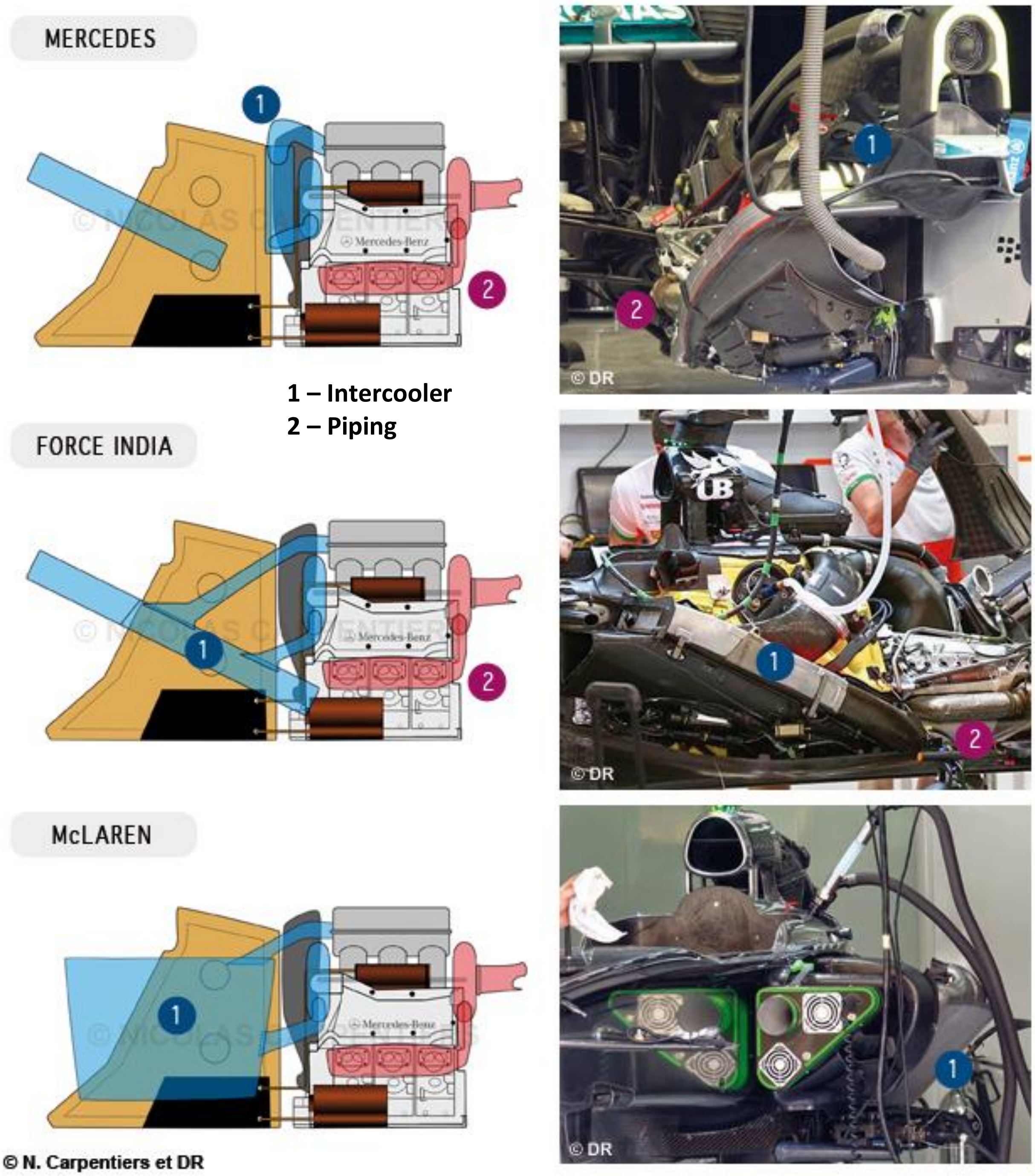
Other priorities

While Renault has retained the classic exhaust pipes which come from the engine and go to the turbine, Mercedes truncated them to integrate them into a single collector, very short ("log manifold", see the image above), placed very low. To simplify, the Brixworth engineers chose to sacrifice some of the combustion engine power, unlike the engine of Viry and Maranello, which would have favored the optimization of exhaust heat V6, at the expense of compactness and the amount of energy supplied to the turbine and then recovered by the MGU-H.

Overall, the Mercedes would combine the advantages of the Renault V6 (compactness) and those of the Ferrari engine (exchanger outside of the side pods), as summarized Rémi Taffin, head of track operations at Renault Sport:

"Here [pointing to the diagram of the Mercedes], we could say that we have the benefit of both, since they can have the MGU-H in V while having an exchanger somewhere in the chassis, which thus takes no place in the side pods. By cons, this architecture has other constraints with a remote compressor turbine, the shaft is very long, which poses other problems, including dynamic ... On the other hand, the question must be transient asked: this is turbo engines, with response time. The pipes here [at Renault] are longer than there [Mercedes]. "

The theoretical flaw of this implementation is indeed the unusual length of the shaft, making the most vulnerable part: led to 125,000 revolutions / minute (the turbine rotation speed, not to be confused with the engine speed), the shaft must have an exemplary reliability, which is the case on the Mercedes unit.

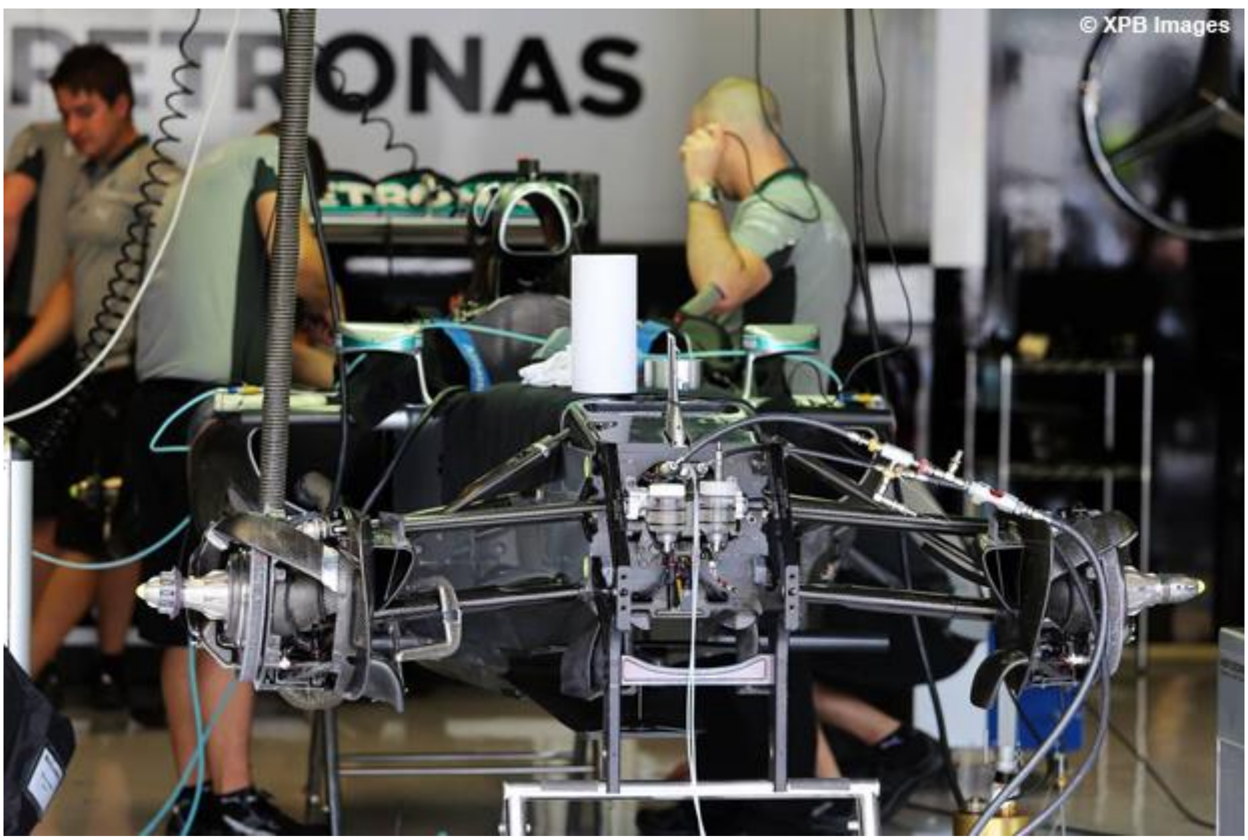


Équipe d'usine par rapport aux écuries clientes

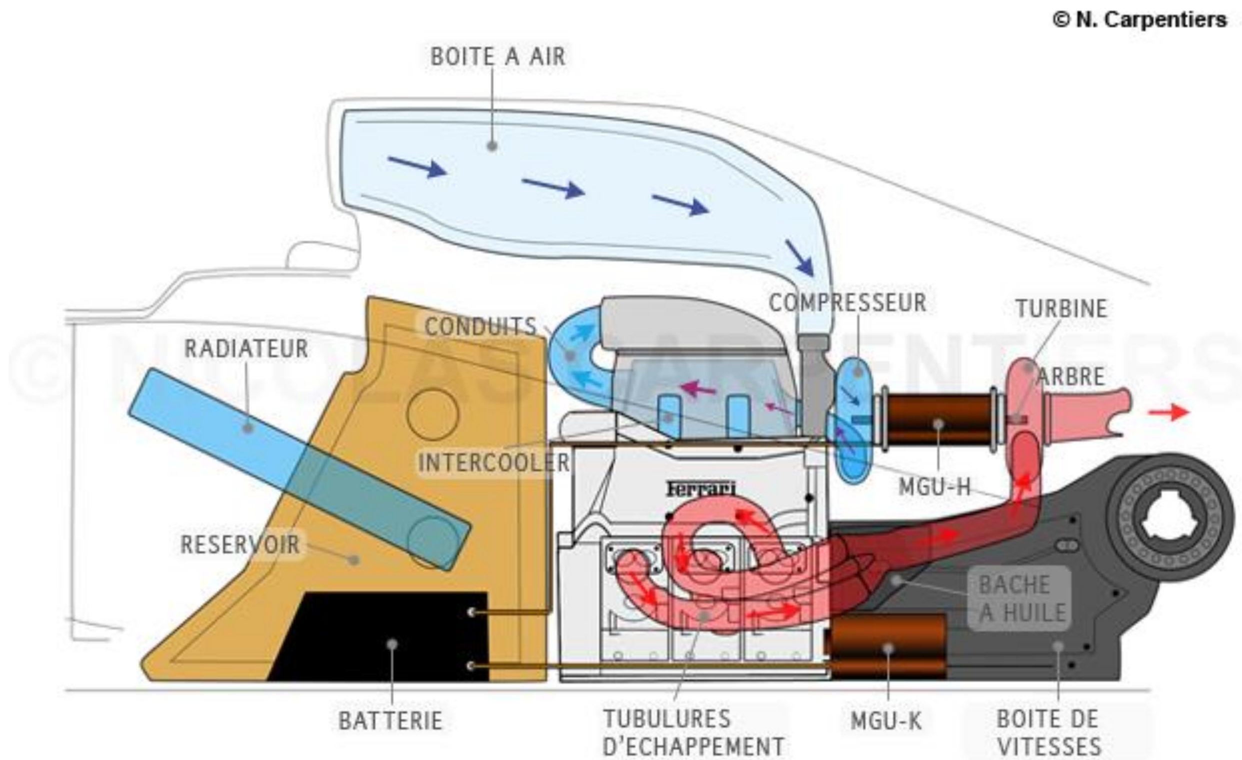
Compare to McLaren, Force India and Williams, the Mercedes factory team had more flexibility and time to optimize the installation of the V6 and refine the internal aerodynamics of his car. The W05 is thus the only car to accommodate its exchanger - air / water - between the engine and the tank, a solution which reduces the length of the compression piping while freeing the inside of the side pods, which may therefore be symmetrical.

The VJM07 designed by Andy Green and his team has, in turn, a single air-air heat exchanger (not split, as the Red Bull, a sign that the German motor perhaps requires less cooling than the French V6). Located in the left side pod, it is also placed forward as possible to the thermal block, to be away from the heat generated by the engine and exhausts, while water and oil radiators for cooling the engine and transmission are in the right side pod.

The Mercedes V6 is integrated almost in the same way in the McLaren. The MP4-29 also hosts an air-air heat exchanger in the left side pod, but by mopunting it oblique, which is quite unconventional. The customer teams have received their power units later than the factory team and therefore had less time to study the details of its integration into the chassis ... Better than Renault (but also Ferrari, yet manufacturer), Mercedes has managed the challenge of integration, making work closely and very early Brackley brains with those of Brixworth, installed each other to forty kilometers.



6.3 THE INTEGRATION OF THE POWER UNIT FERRARI 2014

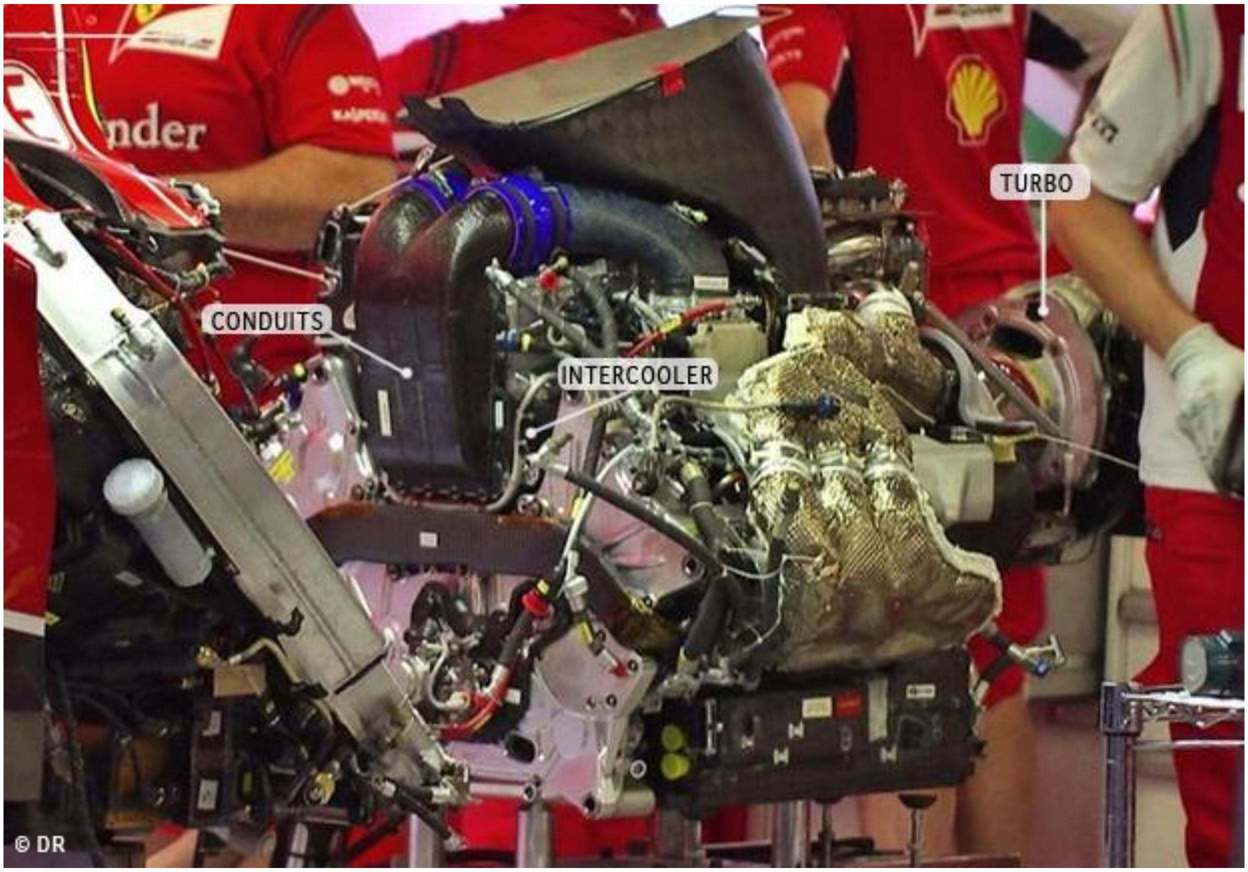


Innovative Installation

To meet the energy efficiency requirements imposed by the 2014 regulations, the engine manufacturers engaged in this 2014 season - Renault, Ferrari and Mercedes - have each taken different paths. We will now closely examine the specifics of the Ferrari engine.

On the paper, the technical daring bet tempted by the Cavallino on its powertrain was not unfounded: designing a compact engine as possible, situated very forward to clear the rear of the chassis and optimize the aerodynamics of the car. After being sacked by Ferrari last August, the chief engine Luca Marmorini explained to his longtime friend Leo Turrini philosophy which had presided over the design of the 059/3 block:

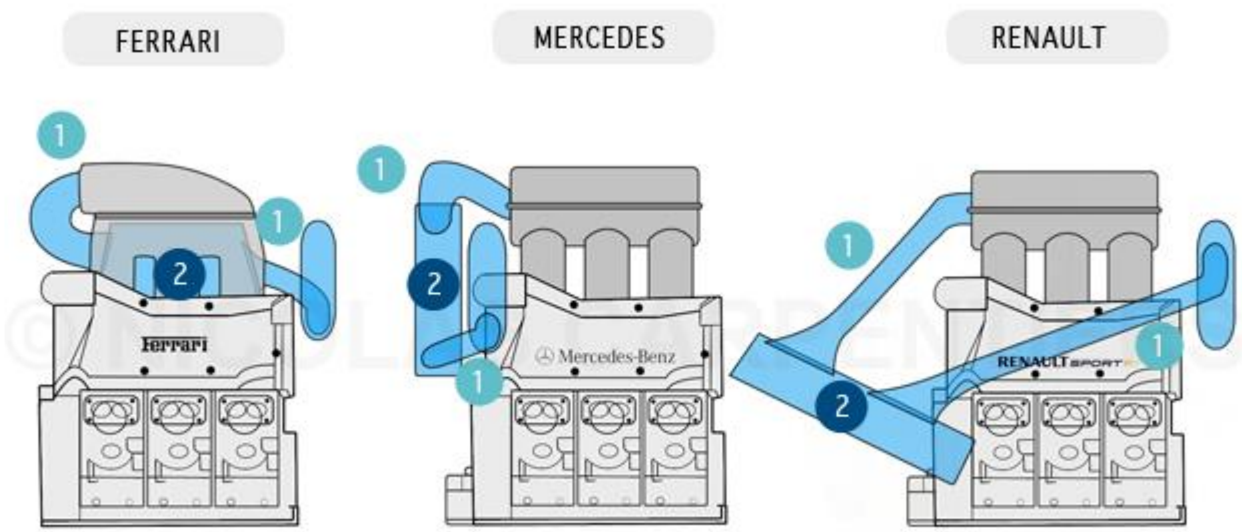
"With my team, I designed a 'power unit' with precise dimensions, smaller than those of Mercedes and Renault, at the express request of the project manager, Mr. Tombazis. They said: 'We want a very compact engine, with small radiators, and we will compensate for the power loss by aerodynamic solutions that will give us an advantage over cars powered by Mercedes or Renault. This is exactly what we did. Except that when we faced our competitors on the track, the horses were missing, of course, but without any compensation from the aerodynamic side! " Whether to take such statements with caution, it must be noted that everything was done on the Italian mechanics to give it the most compact dimensions, obviously at the expense of its intrinsic efficiency.



Even more original

First, Maranello engine housed exchanger inside the "V" formed by the two rows of cylinders. On the Mercedes, this heater is placed in the monocoque in a central position in front of the engine. On the Red Bull-Renault, two large heat exchangers are installed on each side of the engine in the side pods. Italian engineers, meanwhile, used a single exchanger, located in the heart of the V6, to clear as much as possible within the side pods and thereby reduce the blockage of airflow. To recall, the heat exchanger cools the compressed air using water (Ferrari, Mercedes, Lotus) or using air (Red Bull), whereas conventional water heaters and oil, housed in the side pods cool the V6, the transmission, etc.

Very elegant in terms of packaging, this very compact design allows to use of very short pipes to connect the compressor to the heat exchanger (more than the Renault anyway), which should, in principle, reduce the famous "response time" of the turbo. However, this implementation is probably not ideal from a thermal point of view, since the system supposed to cool the compressed air is embedded between the two hot banks of cylinders. Therefore, the water jacket radiator is relatively thick, which increases the weight of the whole (which exceed by fifteen kilos the minimum weight set by the regulation). Combined with overheating exhausts (see below), this feature makes the Ferrari car particularly demanding in terms of cooling.



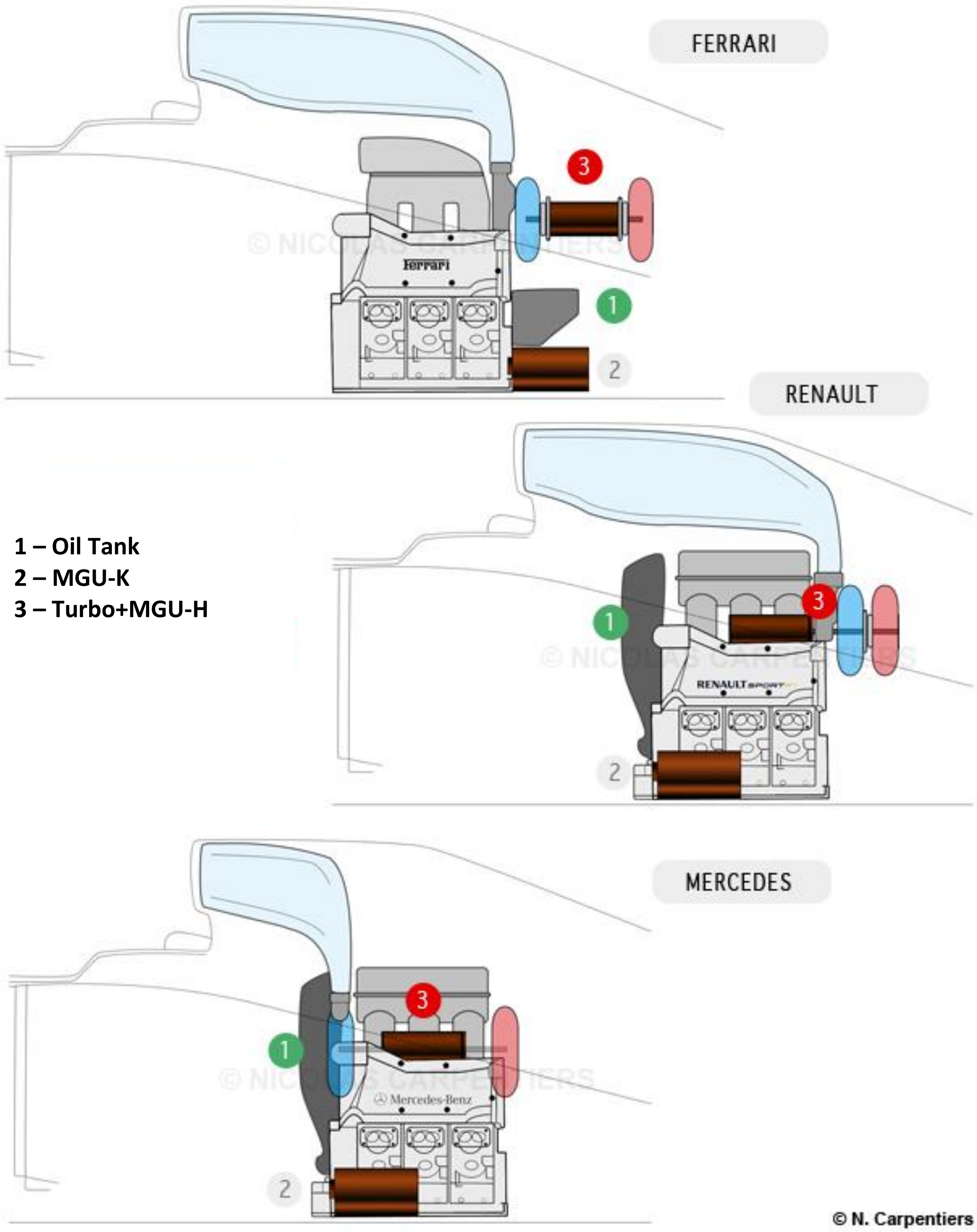
1 – Piping **2 – Intercooler**

© N. Carpentiers

Double wastegate

The V6 Ferrari would be equipped with a compressor and a turbo reduced dimensions, in order to obtain a compact system at the rear of the car. However, while limiting the turbo response time, a small turbine generally produces less power and more against-pressure, which penalizes high-rpm engine power (the Italian power unit is also the only one equipped with a double safety relief valve, resulting in a more bulky piping, etc.). Moreover, given the position of the heat exchanger, turbine and compressor are arranged at the rear of the block.

Like the Mercedes V6, the MGU-H is placed between the compressor and the turbine, but it is located just between the two elements, which it is connected by a much shorter shaft than the German engine. So, the thermal efficiency of the Italian power unit is less than that of its counterpart in Brixworth, not to mention the risks of overheating of the MGU-K due to the rotation of a turbine heated to 900°C.



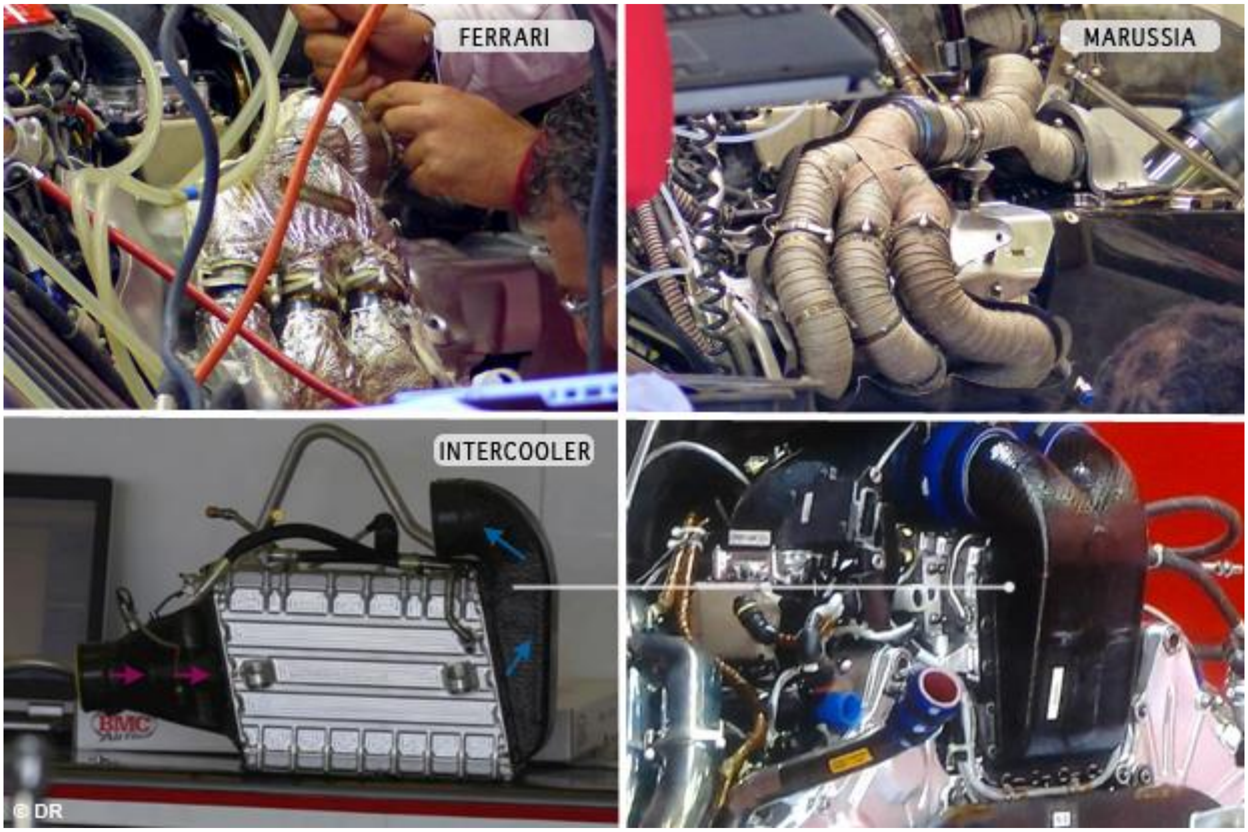
1 – Oil Tank
2 – MGU-K
3 – Turbo+MGU-H

Back to the old…

To clear up the back of the car, the transalpine engine manufacturer adopted a radical solution regarding the position of the oil tank. Since 1998, it is still installed between the chassis and the engine (not near the transmission) because this design ¬- inaugurated sixteen years ago by John Barnard on the Arrows A19 and Alan Jenkins on Stewart SF02 - offers a better center of gravity and shorter lines, and then lighter. On the F14 T, the oil tank is returned in a back position, in the fairing of the gearbox, above the MGU-K, located behind the block. On Renault and Mercedes power units, on the contrary, the collector / generator is located at the front of the V6 on the left. Again, the Scuderia has followed an original route.

Finally, the exhaust pipes - conventional (as opposed to "log manifold" Mercedes) - does not have double walls, unlike those fitted to V6 Renault and Mercedes, and would clear the sudden lost of calories. To remedy this, a solution first tested by Marussia, appeared at the Belgian Grand Prix: the exhausts were covered with a kind of flexible metal foil, to hold the heat in the pipes, increasing the exhaust velocity of the flue gas and, hence, the rotational speed of the turbine. Note however that the cylindrical tubing Mercedes is also covered with an insulating cover.

The radical architecture of the 059/3 - integrated in identicaly in the Sauber and the Marussia - is the result of the prerogative granted by Maranello in aerodynamics compared to specific performance of the hybrid engine. But that's not all. As clever as it is, a drawing must be fully implemented - including the electronic level (ERS is a weak point of the Italian motor) - to bring the expected benefits. Thus the same choice architecture can they be successes or failures: Mercedes and Ferrari have decided to place the heat exchanger in the center of the chassis, in order to clear the side pods and optimize the internal aerodynamics.


FERRARI
MARUSSIA
INTERCOOLER
BMC
© DR

7. The F1 Power Units 2015.

[Source: http://www.f1i.com – Nicolas Carpentiers]

7.1 THE FERRARI POWER UNIT 2015

7.1.1 The 059/4

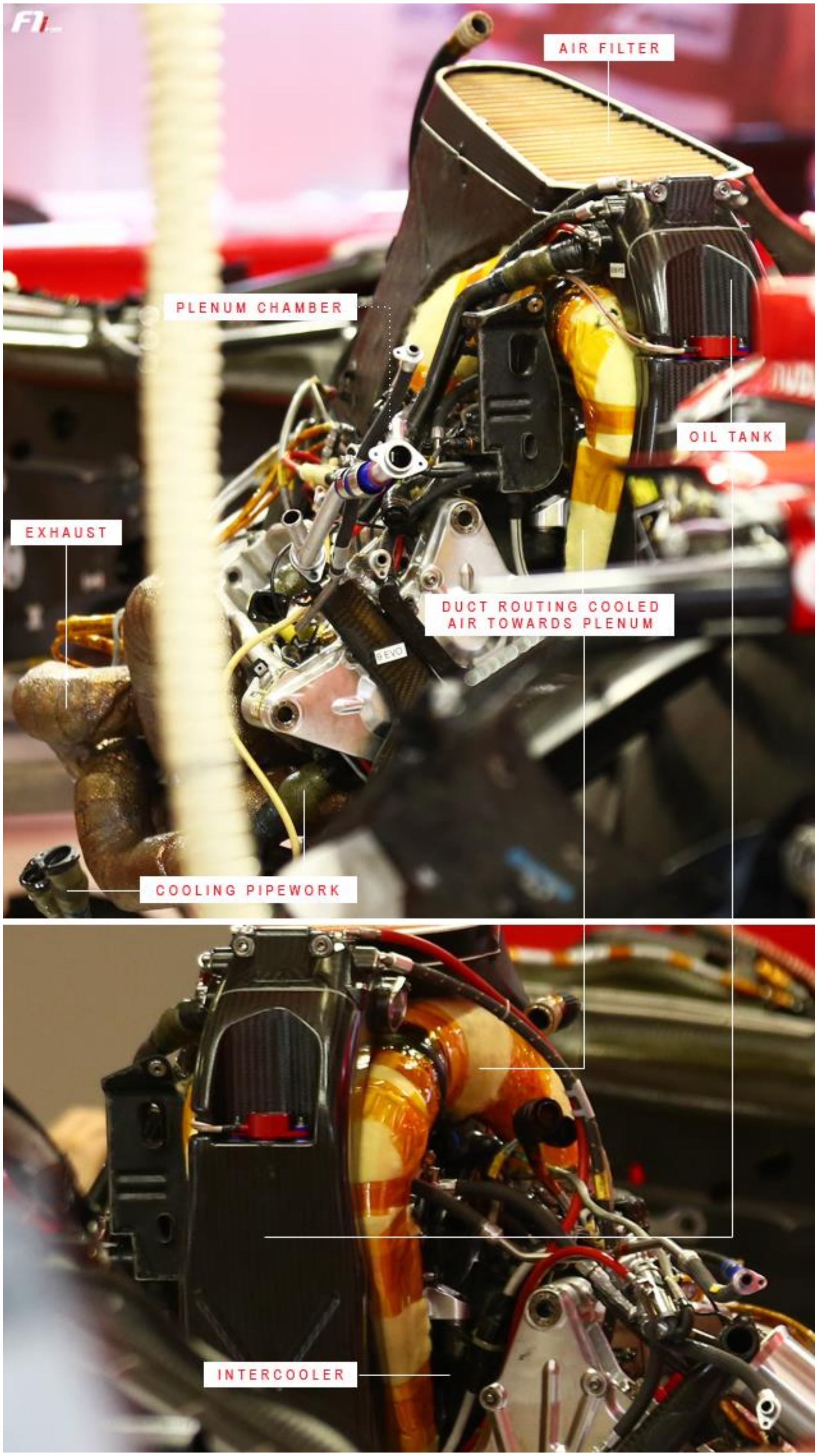
GOING BACK TO THE ROOTS…

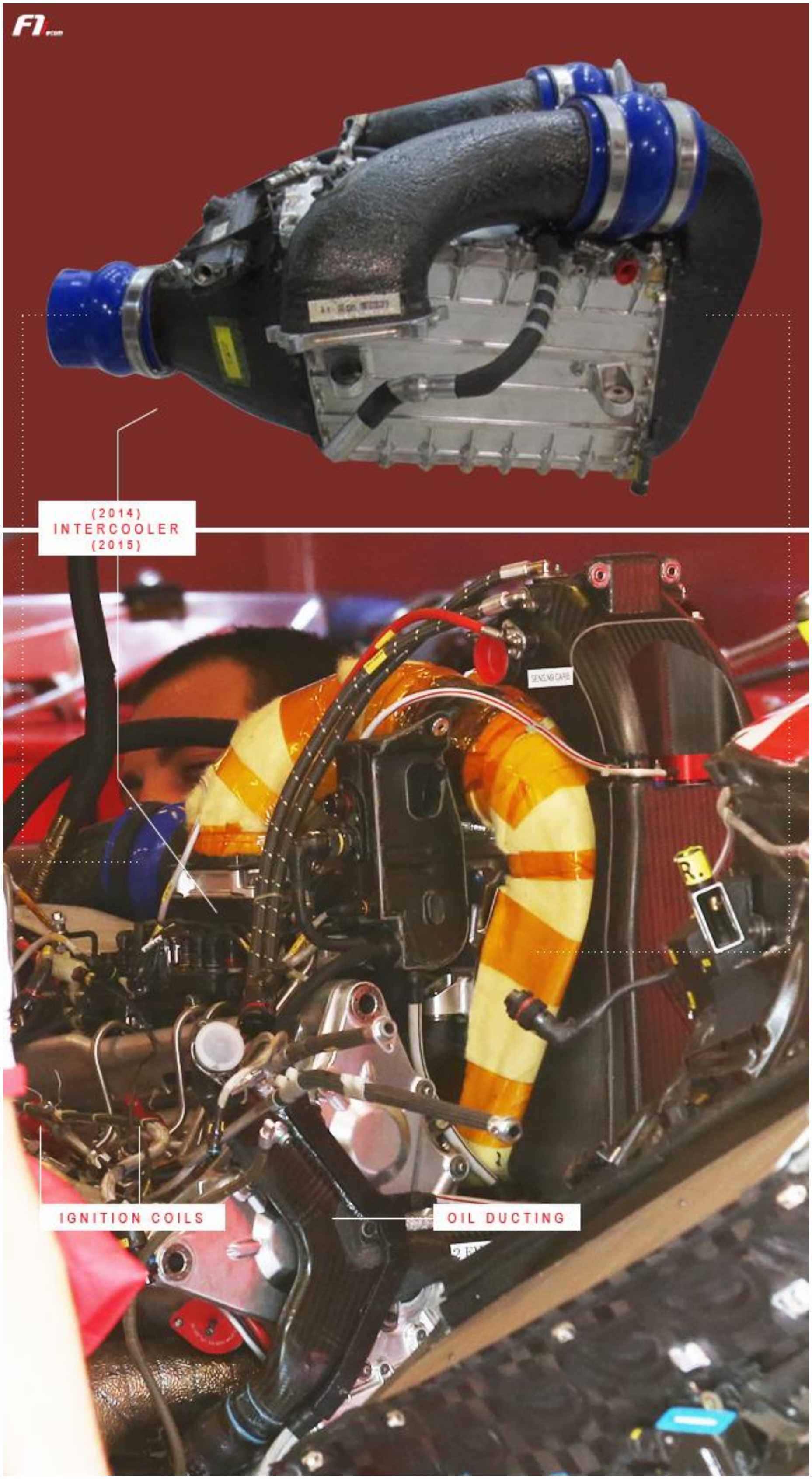
Formula One can be seen as a schizophrenic sport, always striving to move forward and drawing on the brightest minds and most sophisticated technology in order to... go around in circles as fast as possible. Last year saw F1 reconnect with its past; after seven years of frozen development in the normally aspirated V8 era, the engine became crucially important once again. The pinnacle of motor racing had gradually turned into a one-dimensional sport with performance relying almost exclusively on aerodynamics. F1's big hitters thus devised a new formula that aimed at finding more balance between aero, engine, V6 integration within the chassis, energy recovery, etc. Except that engine performance has simply become the new name of the game.

Granted, engine engineers have been put in the spotlight once again but the new technologies are so young and ground-breaking that it immediately created big gaps between the power units. Manufacturers were initially supposed to homologate their units before the start of the 2015 campaign, but this changed when Ferrari and Renault found a loophole in the technical regulations and the FIA allowed in-season engine development. Still, playing catch up with Mercedes, which has been the clear benchmark over the past two years, remains extremely difficult. This looked like an even taller order for Ferrari coming off its worst campaign in over two decades, but the revered Italian outfit managed to make some in-roads into Mercedes' advantage. In order to achieve such feat, Ferrari head of engine operations Luigi Fraboni explains that Maranello's power unit was given a complete overhaul last winter.

"We started with last year's engine [the 059/3] as a basis, but we developed it to a much better product," he is quoted as saying by *Racecar Engineering*. "But we realised there were others better than us so we reworked everything.
"A big effort went into combustion, we looked at the turbo, getting the most out of the energy recovery and we did a lot on the oil system. We looked at better knock control too, and we had to get better correlation between the software and how the engine worked in reality. In the end, we ended up with basically what is a completely new engine."

Changes are not visually striking, save for the oil tank being placed at a different place. On the 2014-spec F14 T, it was positioned at the back of the internal combustion engine [ICE] and sat within the gearbox casing, right above the MGU-K. That installation used to be commonly used… before 1998! This year, the oil tank occupies a more traditional spot, namely between the chassis and the engine. Such assembly improves the package's centre of gravity and allows for shorter and lighter pipework. The oil tank is separated from the engine when the latter features a dry pump system. F1 cars have elongated oil tanks, as this shape is better suited to cope with centrifugal forces in the corners.


AIR FILTER
PLENUM CHAMBER
OIL TANK
EXHAUST
DUCT ROUTING COOLED AIR TOWARDS PLENUM
COOLING PIPEWORK
INTERCOOLER

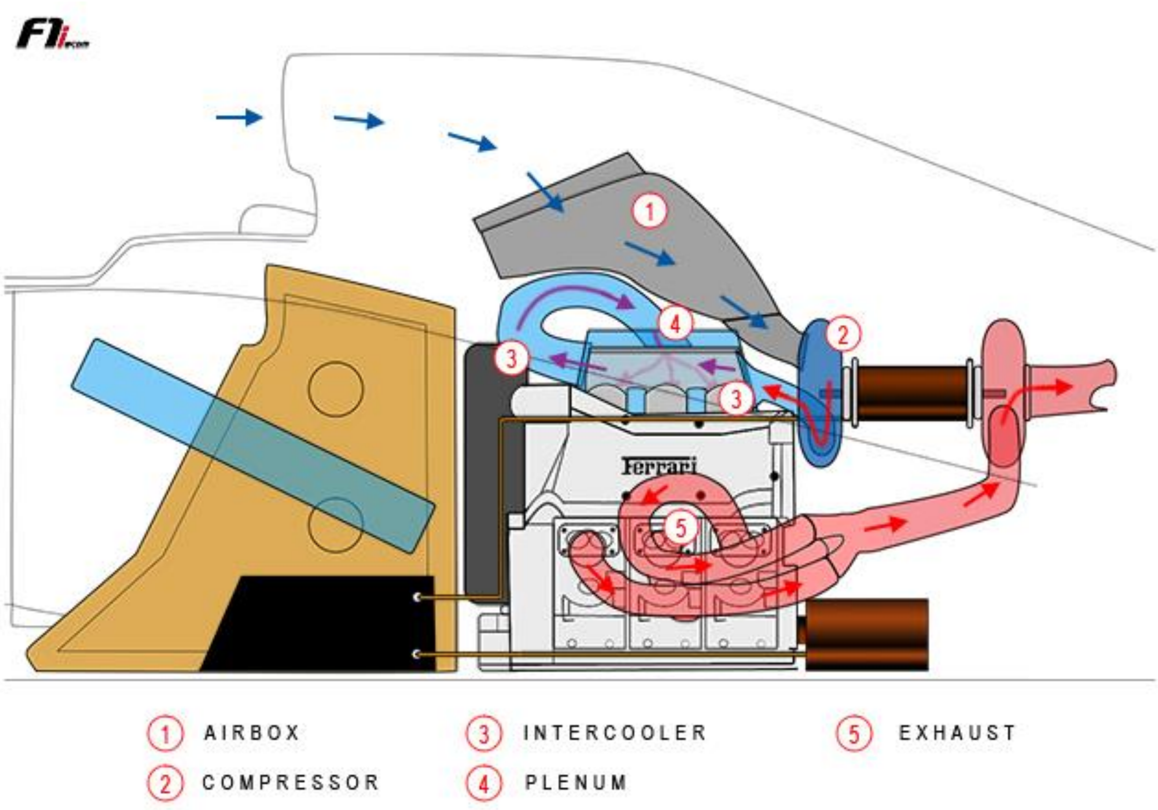

(2014)
INTERCOOLER
(2015)
IGNITION COILS
OIL DUCTING

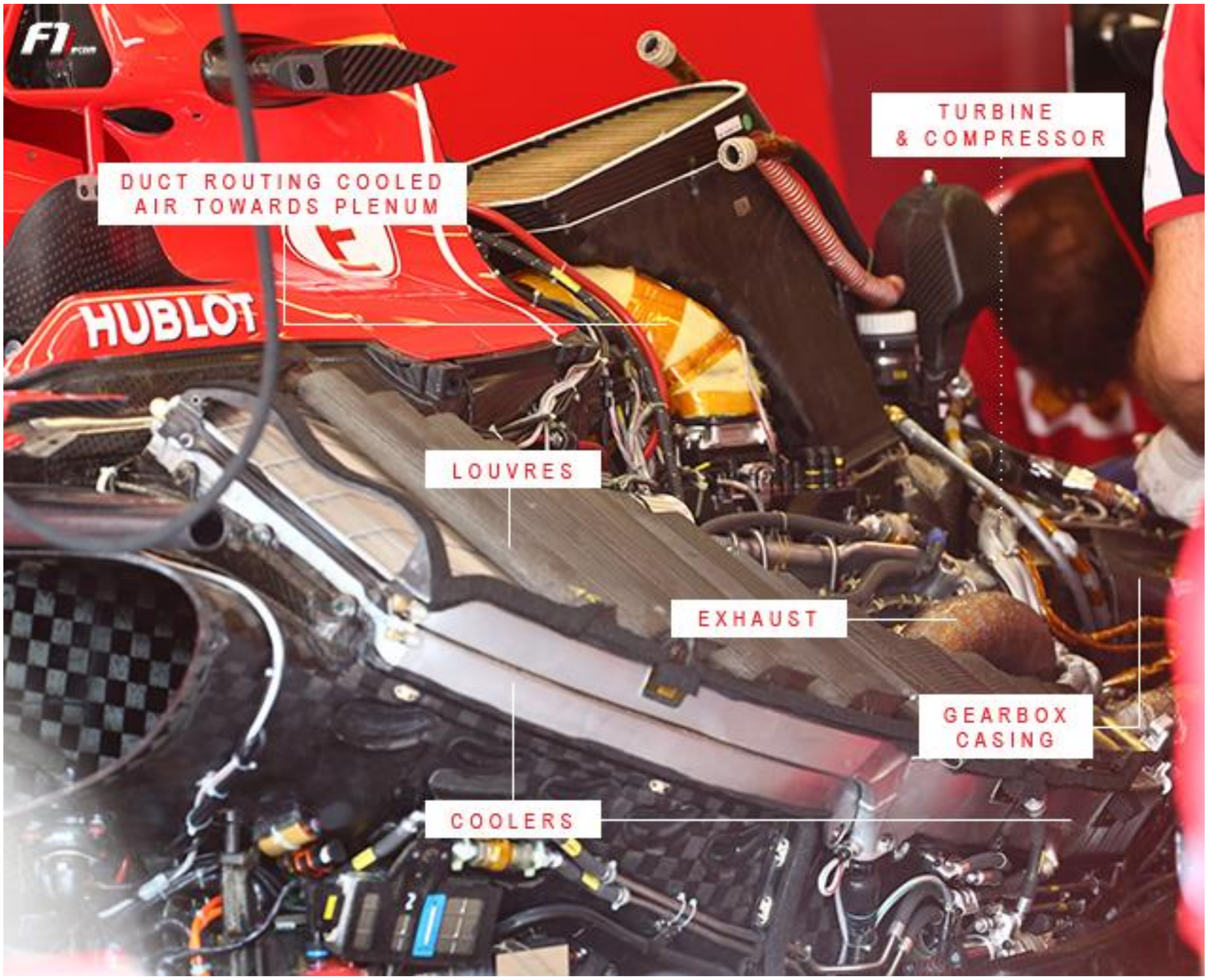
… BUT NOT ALL THE WAY

However, the overall architecture of the V6, which was designed by Lorenzo Sassi under the stewardship of Mattia Binotto, has not been totally revised. The intercooler's shape may have been slightly altered compared to 2014 (see above), but it still sits within the Vee of the engine. As a reminder, its Mercedes counterpart is lodged within the monocoque and ahead of the engine, while we have already mentioned Red Bull-Renault's split-intercooler design, with one element featuring in each sidepod. As for Honda, the McLaren MP4-30 is fitted with a big intercooler in its right sidepod. Ferrari has gone for an air-to-water intercooler (like Mercedes) and placed it at the heart of its engine in order to free up some space in the sidepods, thus limiting airflow resistance.

This very neat and compact package allows having shorter pipework between the compressor and the intercooler – at least when compared to the Renault and Honda architectures. Such design theoretically reduces the infamous 'turbo lag'. However, this installation might not be the best thermally speaking, since the intercooler is lodged between two banks of red-hot cylinders. But Ferrari engineers have managed to stave off any potential issues by improving the SF15-T's overall cooling.

On the picture above, one can notice that the intercooler ducts are roughly covered with an insulating material in order to preserve the cooling air about to enter the plenum chamber. Below is a diagram describing how the airflow travels in the Ferrari 059/04.





INCREASING THE TURBINE SIZE

Eager to maximise aerodynamics and have a tight rear end on its 2014 charger, the Scuderia ran a very compact turbocharger installation last year. But it ended up compromising outright turbine efficiency, as aero gains did not make up for the lack of engine power. Indeed, a smaller turbine will de facto generate less power and more back pressure, which ends up penalising the internal combustion engine (ICE) in the higher RPMs (since wastegates are quite often open).

“A definite weakness of last year's car was that the amount of electrical energy we were able to recover from the turbo was not really good enough for producing competitive power levels during the race,” Ferrari technical director James Allison admitted when the new SF15-T was launched.

“It was one of the reasons Ferrari's qualifying performance was relatively stronger than race performance last year. We have tried to change the architecture of the engine to make it a better compromise."

When the time came to design the 059/4, Maranello engineers reconsidered the respective importance of engine and aero and decided to increase the turbine's size. The device now sits within the gearbox housing, which also includes part of the manifold, the collector and part of the single exhaust. Having a bigger turbine means that the MGU-H absorbs more power from the turbine shaft, which in turn leads to greater electric deployment. In just one season, Ferrari has succeeded in solving the issues that are currently plaguing Honda. This has been achieved through a less bold but more coherent technological approach, clever recruiting, and massive investment.

What's more, Ferrari's partnership with Shell has been strengthened in order to improve energy efficiency and prevent knock (uncontrolled explosions that disrupt the combustion process).

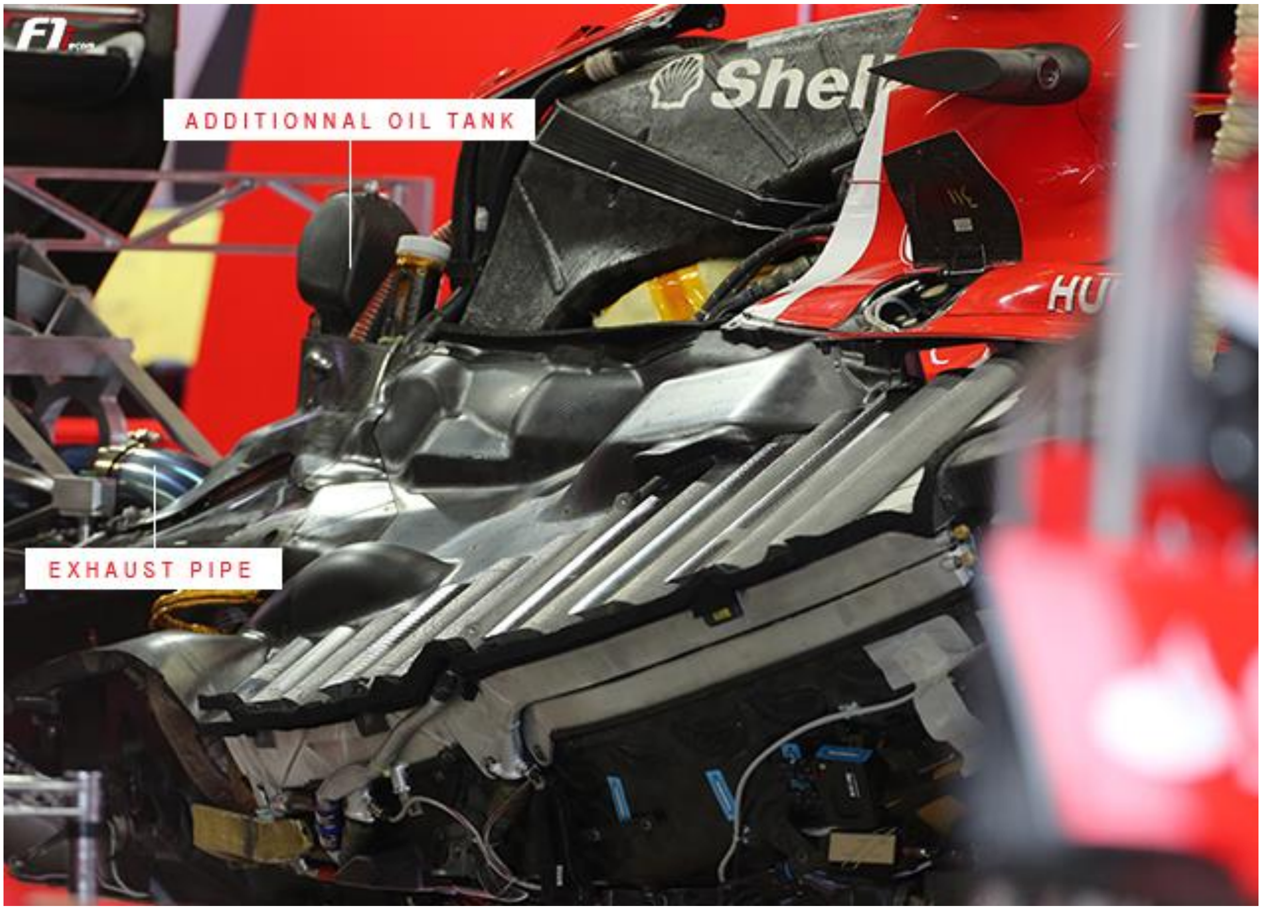
"Last year we were developing in parallel with Shell, but this year we have set targets to them in terms of performance and especially knock," Fraboni added. "They now know where we want to go and what we want to achieve with the engine and they have to get there.

"So each time we go to the dyno, they will bring candidate fuels to test to make sure we have the best for the races. I think now it is a very close relationship."

When all combined, these evolutions would have unlocked an extra 60bhp on the Italian power unit (though only Maranello engineers actually know how much ground they have made) and enabled Ferrari to cut the gap to Mercedes.

On the picture above, one can easily spot the radiators, which have a flatter positioning and feature a clever system of louvres that can better channel the airflow on entry and exit.

Next page, one can also notice that most components have been streamlined in order to improve insulation and internal aerodynamics.

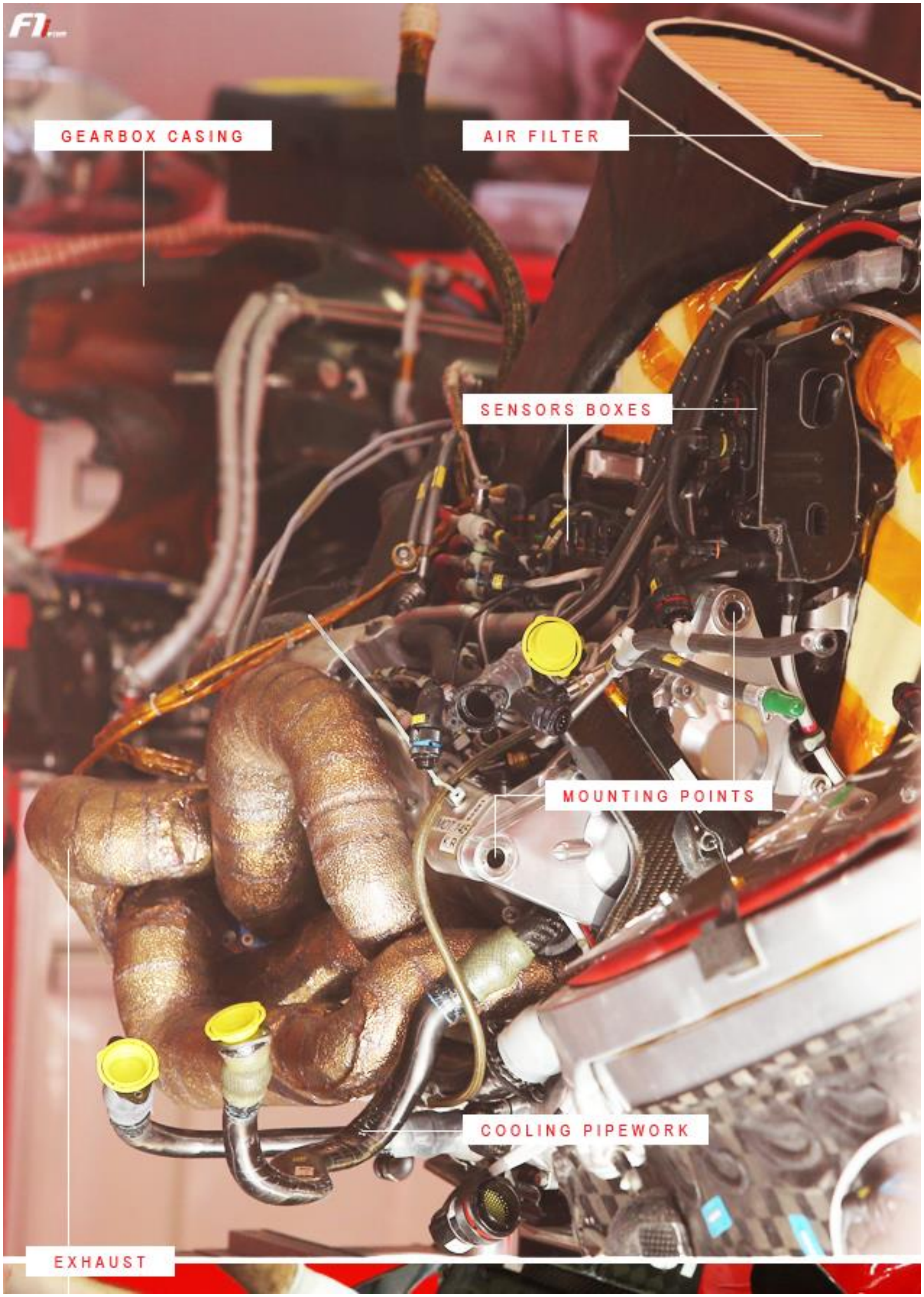

ADDITIONNAL OIL TANK
EXHAUST PIPE

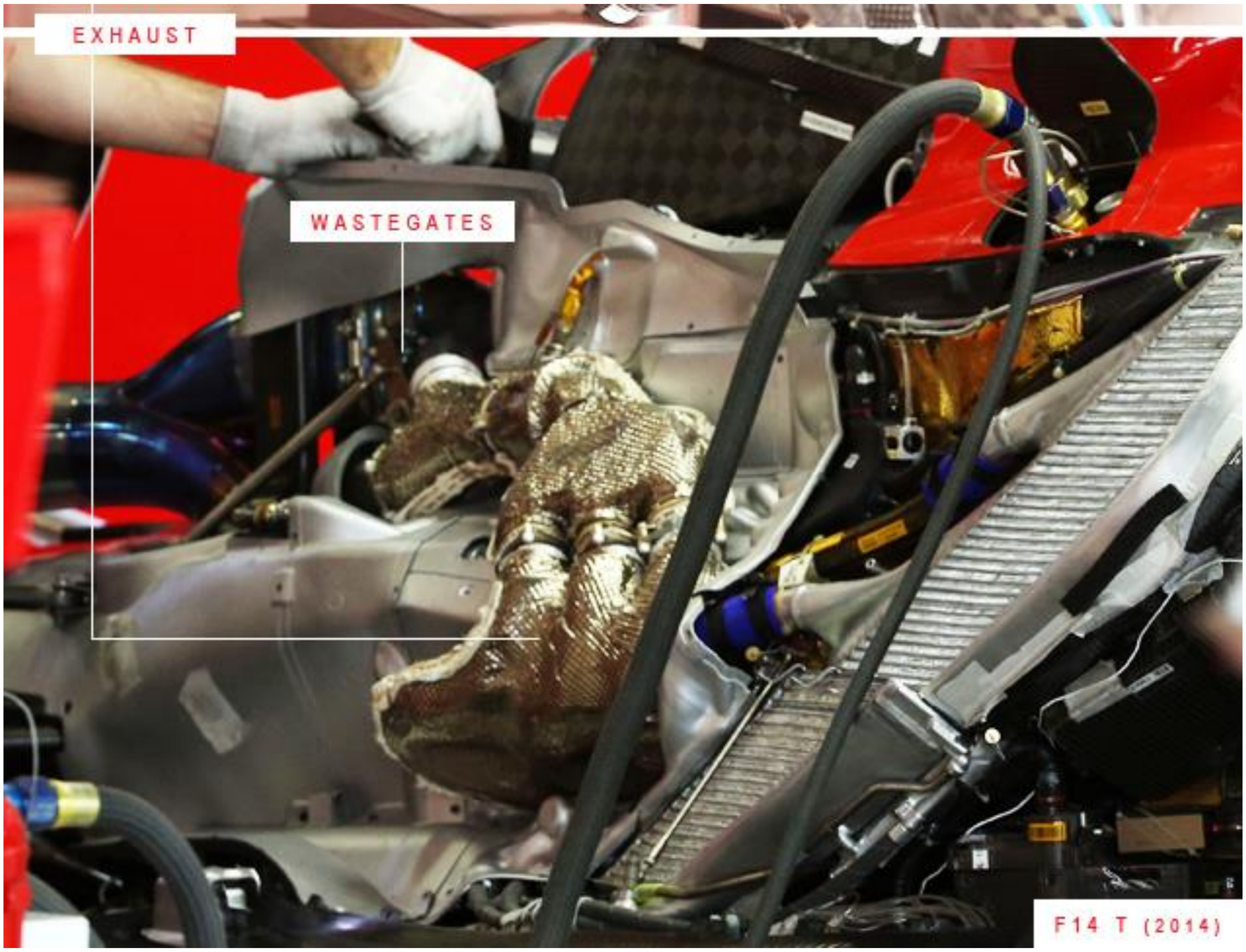
A LESS TWISTY DESIGN

Last year's 059/3 had a very long manifold, that would climb upwards along the ICE and wrap around it.

The new-for-2015 pipework is shorter, more compact, and less twisty. Thus, it can feed more power to the internal combustion engine, while also making the turbine work more efficiently. The latter can produce more energy, which in turn benefits the MGU-H. The tubes sit closer to the car's floor, reaching the turbine from below. Said turbine seems to have been lowered, while the wastegates installation is also different from last year.

Also worth noticing are the yellow-sealed ducts used to feed cooling air to the engine. Water circulation inside the engine was one of the first examples of CFD (computational fluid dynamics) application. This is due to a high degree of correlation between simulation and reality, as the liquid is flowing in a closed circuit (CFD applications on aerodynamics are a very different story).


GEARBOX CASING
AIR FILTER
SENSORS BOXES
MOUNTING POINTS
COOLING PIPEWORK
EXHAUST


EXHAUST
WASTEGATES
F14 T (2014)

LOOKING AHEAD TO 2016

Ferrari's MGU-K was kept at the back of the ICE, a different position compared to the Mercedes, Renault, and Honda installations. All other engine manufacturers have their motor-generator units placed on the left-hand side of the V6 and towards the front. It seems that Maranello actually intends to do the same in 2016 in order to further declutter the rear of its next car (without compromising engine performance like it did last year).

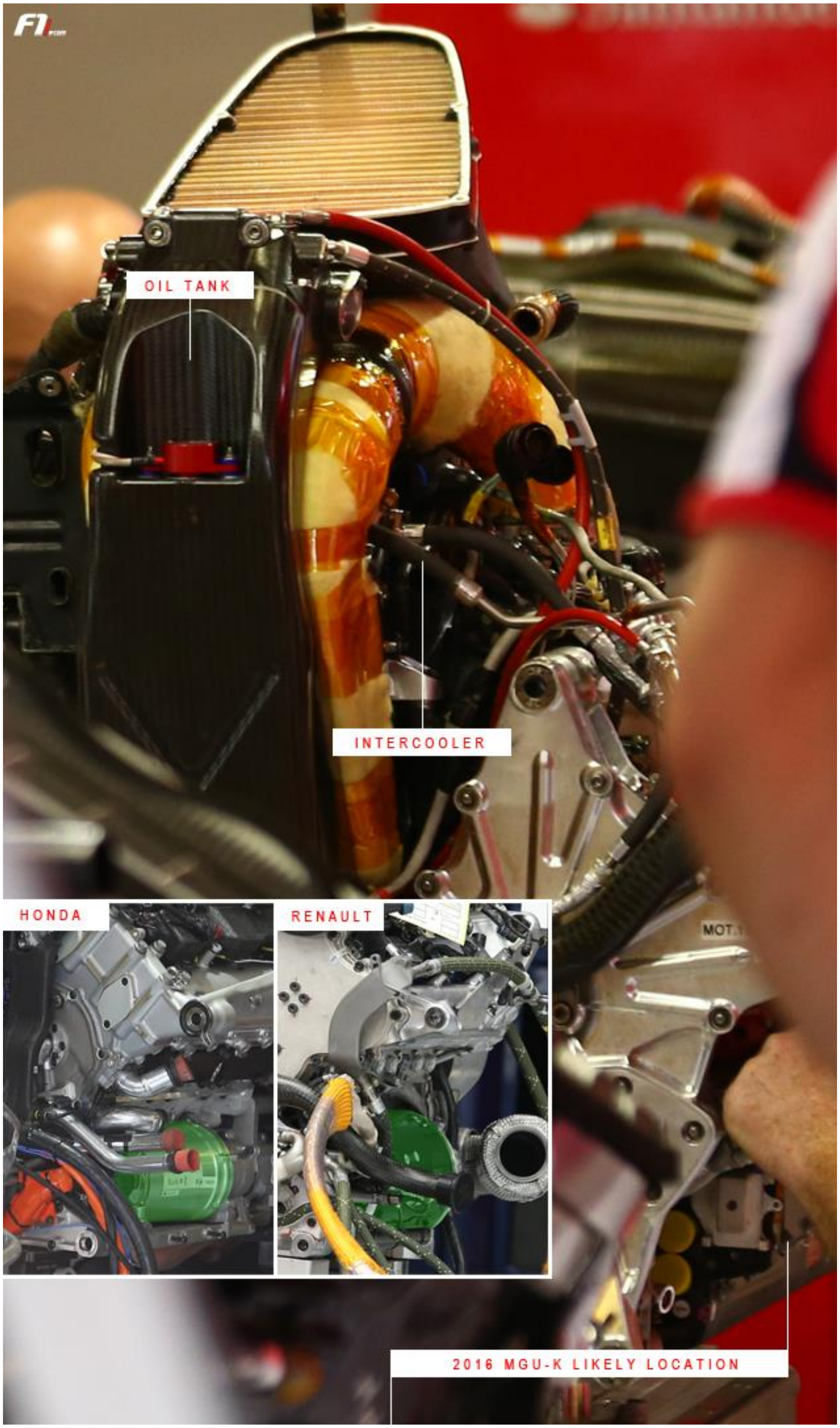
After introducing upgrades in Canada and Italy, Ferrari was supposed to spend its final four tokens ahead of Austin in order to enhance its V6 and prepare 2016. Yet, while the latest specification does improve overall engine reliability (which does not cost any token), it was not the prototype version people had expected to see. When asked about what Ferrari had in the pipeline for next season, Sassi had remained quite vague.

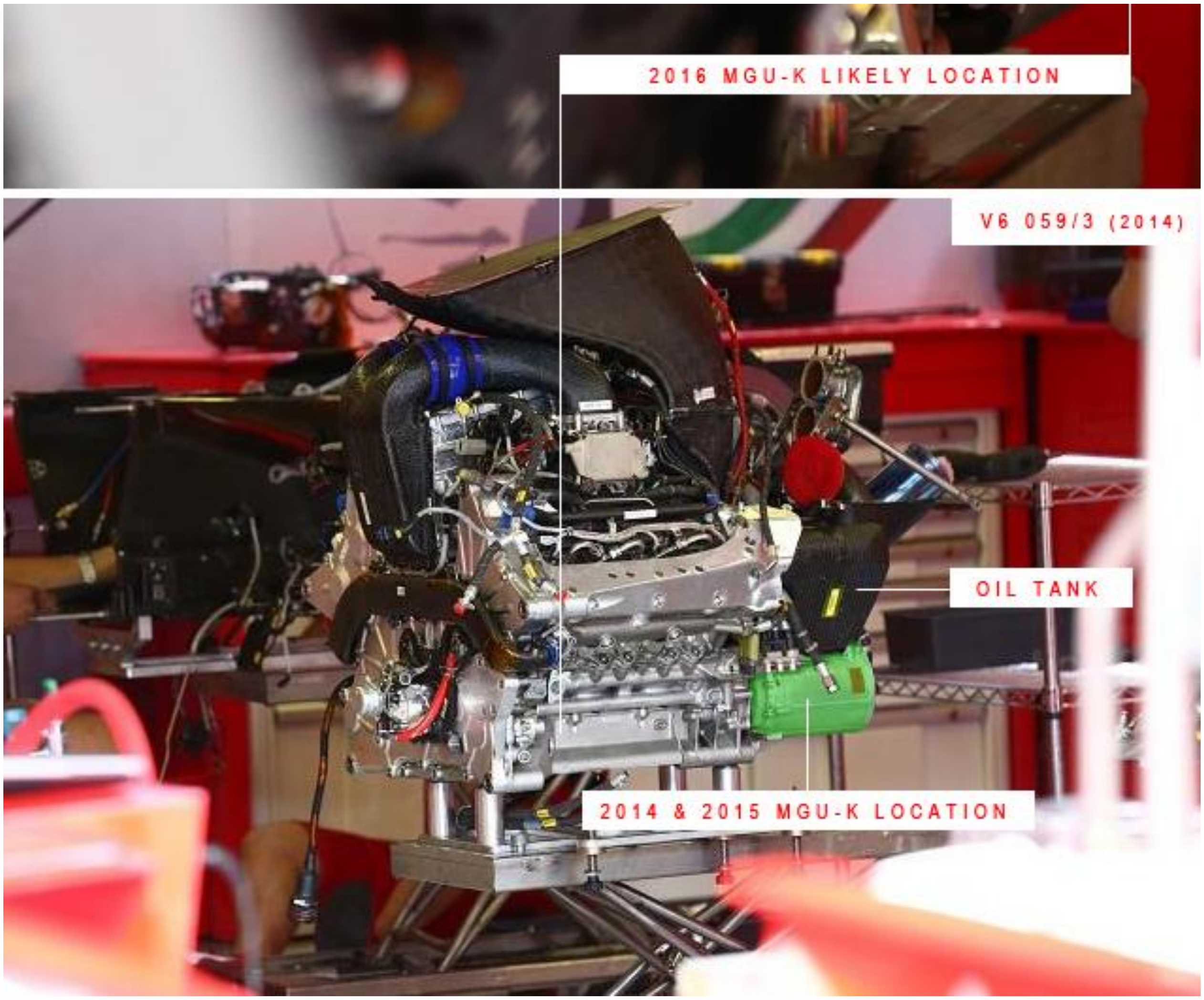
"As for our development tokens, we still have four left and plenty of ideas on how to spend them, both on increasing power for this season and also looking ahead to 2016," said the chief power unit designer.

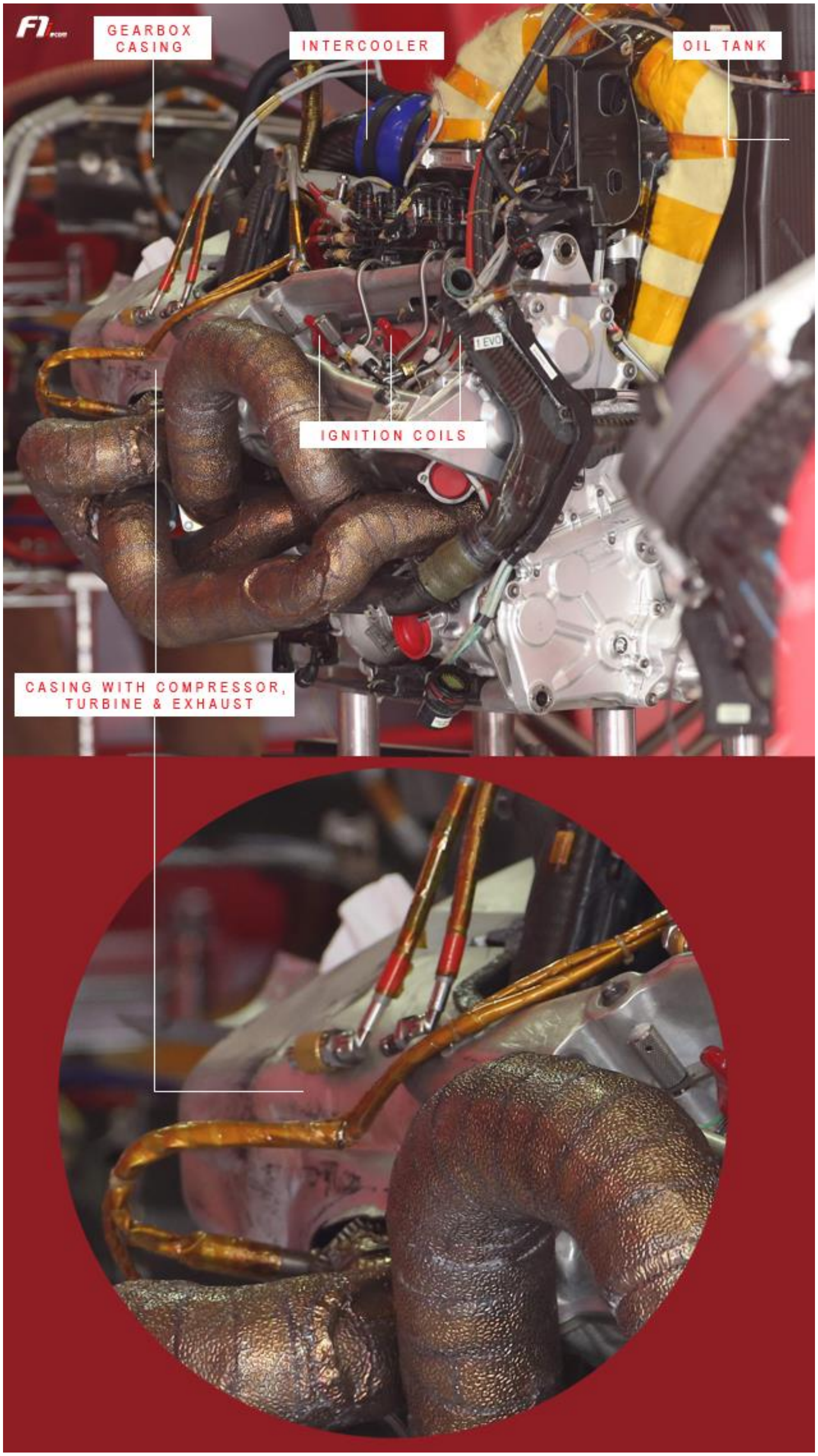
It must be noted that time is less critical this year, with engine manufacturers all agreeing to have the power unit development restrictions relaxed for 2016 (the decision still needs to be ratified during the next World Motor Sport Council meeting in December). In-season development will be allowed once again, while the number of allocated tokens will stay at 32 when it was supposed to decrease to 25. Furthermore, the components that were supposed to become totally frozen (as per Appendix 4 of the technical regulations) will finally be open to modifications. These include the upper/lower crankcase, the valve drive, the covers, part of the crankshaft, the air valve system, and ancillaries drive.

After poaching top personnel from rivals – like former Mercedes man and combustion specialist Cédric Cornebois – Maranello engineers look to use this greater leeway to make the Prancing Horse gallop again.

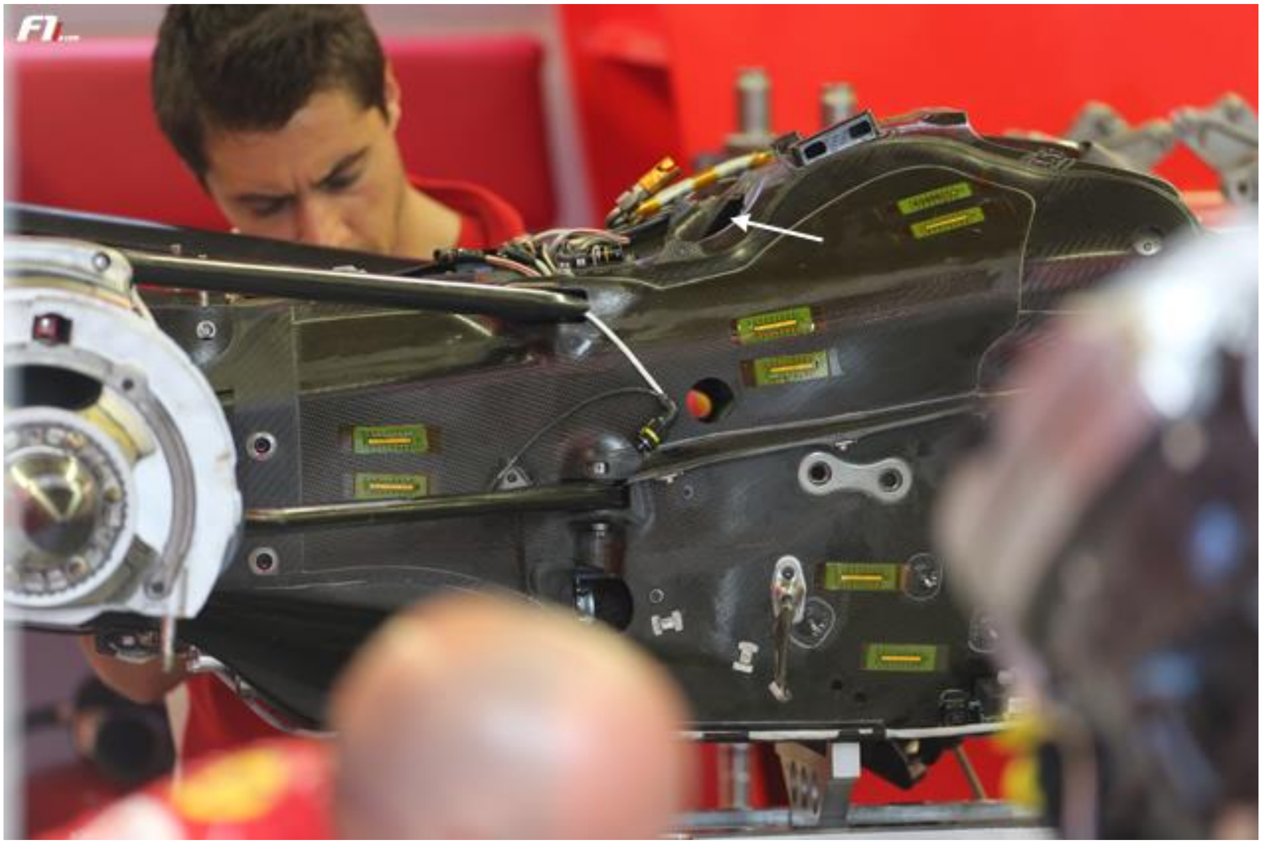
"The engine is still at the beginning of its development and we are still having new ideas each week, there is still much more to come," Fraboni concluded. But will it be enough to eclipse the Silver Arrows?


OIL TANK
INTERCOOLER
HONDA
RENAULT
2016 MGU-K LIKELY LOCATION


2016 MGU-K LIKELY LOCATION
V6 059/3 (2014)
OIL TANK
2014 & 2015 MGU-K LOCATION


GEARBOX CASING
INTERCOOLER
OIL TANK
IGNITION COILS
CASING WITH COMPRESSOR, TURBINE & EXHAUST

7.1.2 The Ferrari Magic Gear Box



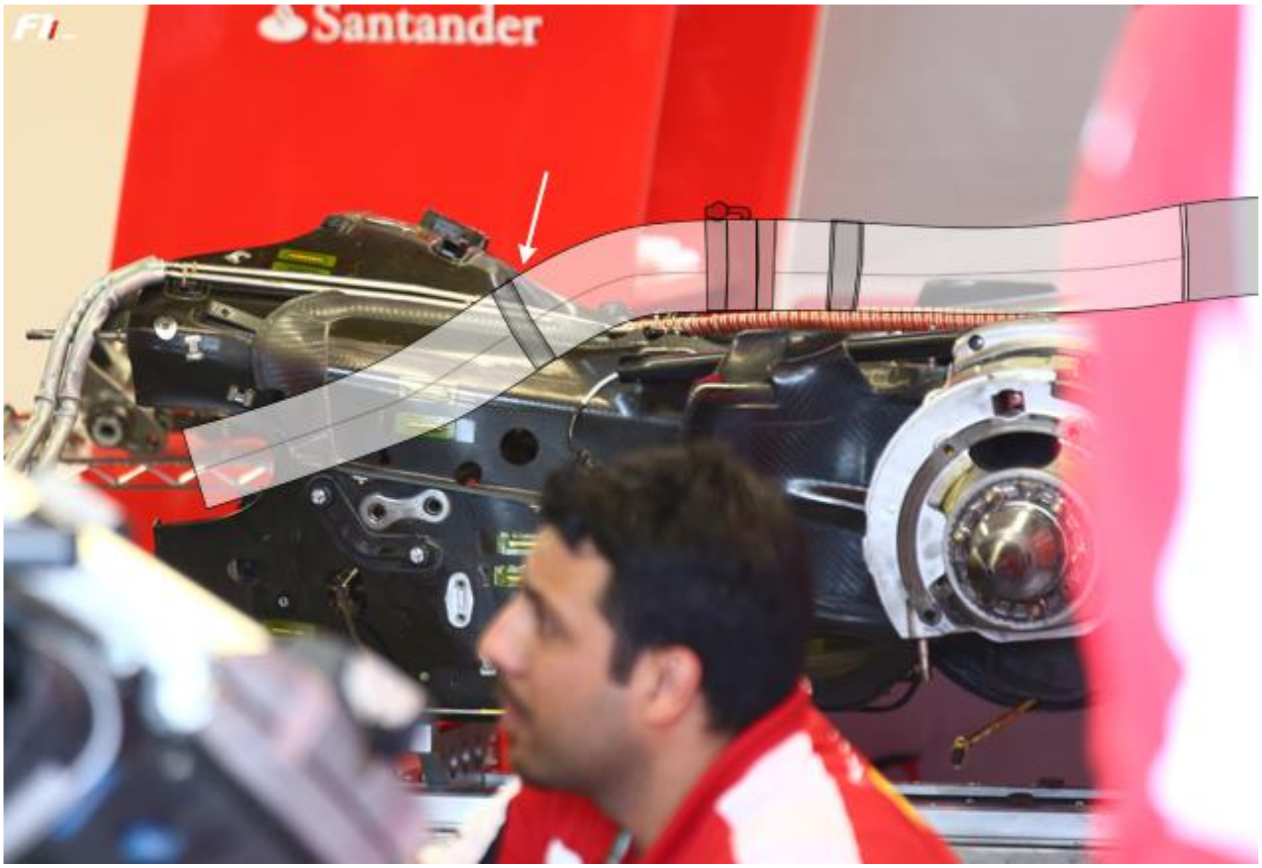
Technical director James Allison’s stewardship at Ferrari seems to have rekindled creativity within Maranello’s design department, as highlighted by its original gear case.

Already featuring a new cooling system, this year’s SF15-T also has an innovative rear end. Basically, an F1 gearbox comprises of the clutch, the transmission per se, and a case that is usually moulded in carbon fibre (or cast in titanium). The latter is pretty much the mainstay of the rear chassis and has pickup points to the back of the engine, the pull rod suspension and the rear crash structure. All these features make it an essential component on Sebastian Vettel and Kimi Raikkonen’s latest charger.
For the past two years, Ferrari has been looking to declutter its gearbox and bell housing area. Its engineers and designers had for instance come up with a truly original idea last year, as they had placed the F14 T’s oil tank inside the gear case.

ALL IN THE BOX

This radical solution has been dropped on its successor though, with the oil tank returning to a more conventional position, i.e. in front of the internal combustion engine. Such assembly was first seen 17 years ago on the John Barnard-designed Arrows A19, as well as on the Stewart SF02 conceived by Alan Jenkins. This installation brings several benefits, including an improved centre of gravity, as well as shorter and lighter pipework. On Ferrari's 2015 challenger, the exhaust manifold now occupies the newly freed space.

As seen on the picture below, the pipe goes inside the gear case through a couple of side and oval-shaped apertures, then converge in the collector before the single exhaust, which has been mandatory since 2014, comes out of the top.



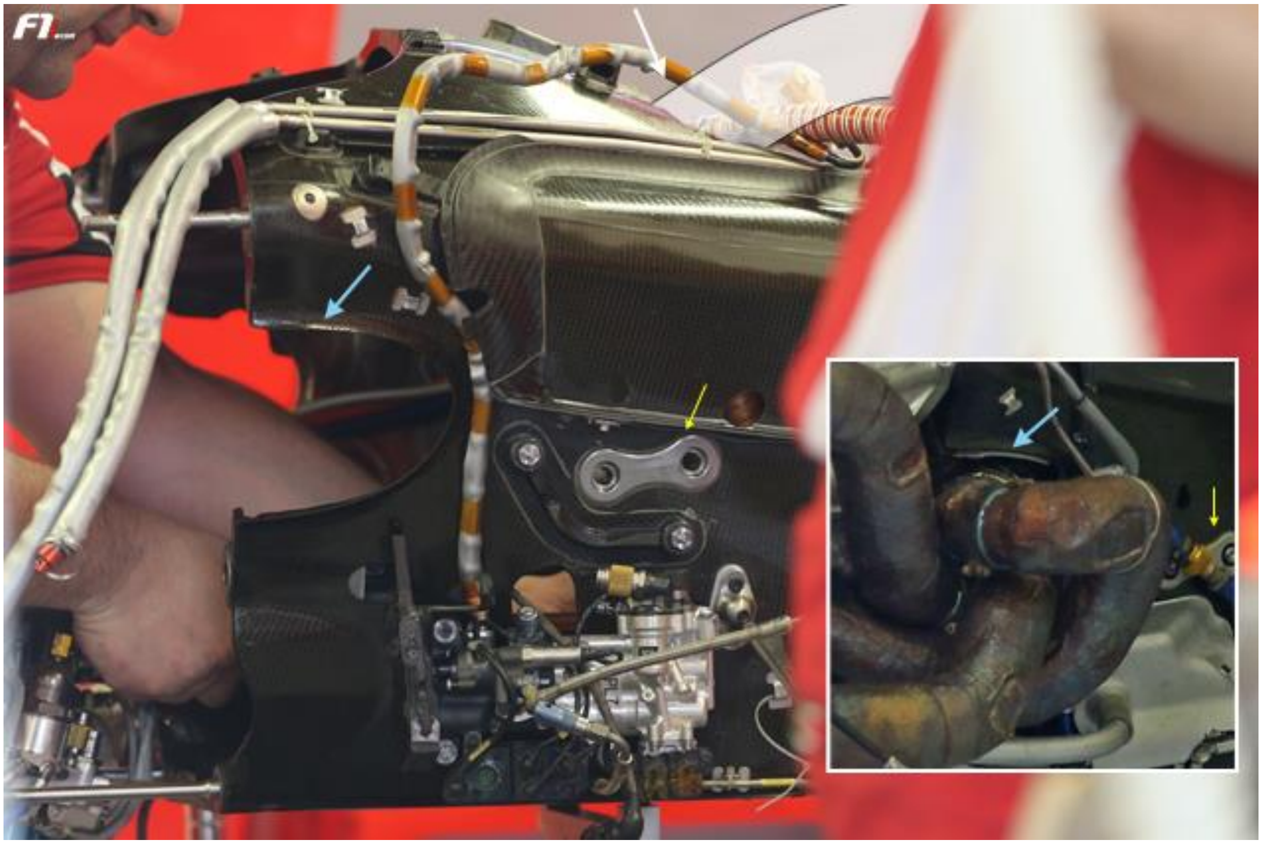
Pictured above is the Sauber installation but the Swiss outfit is supplied by Ferrari and therefore uses the same hybrid power unit (ICE + ERS), gearbox, gear case and manifold.

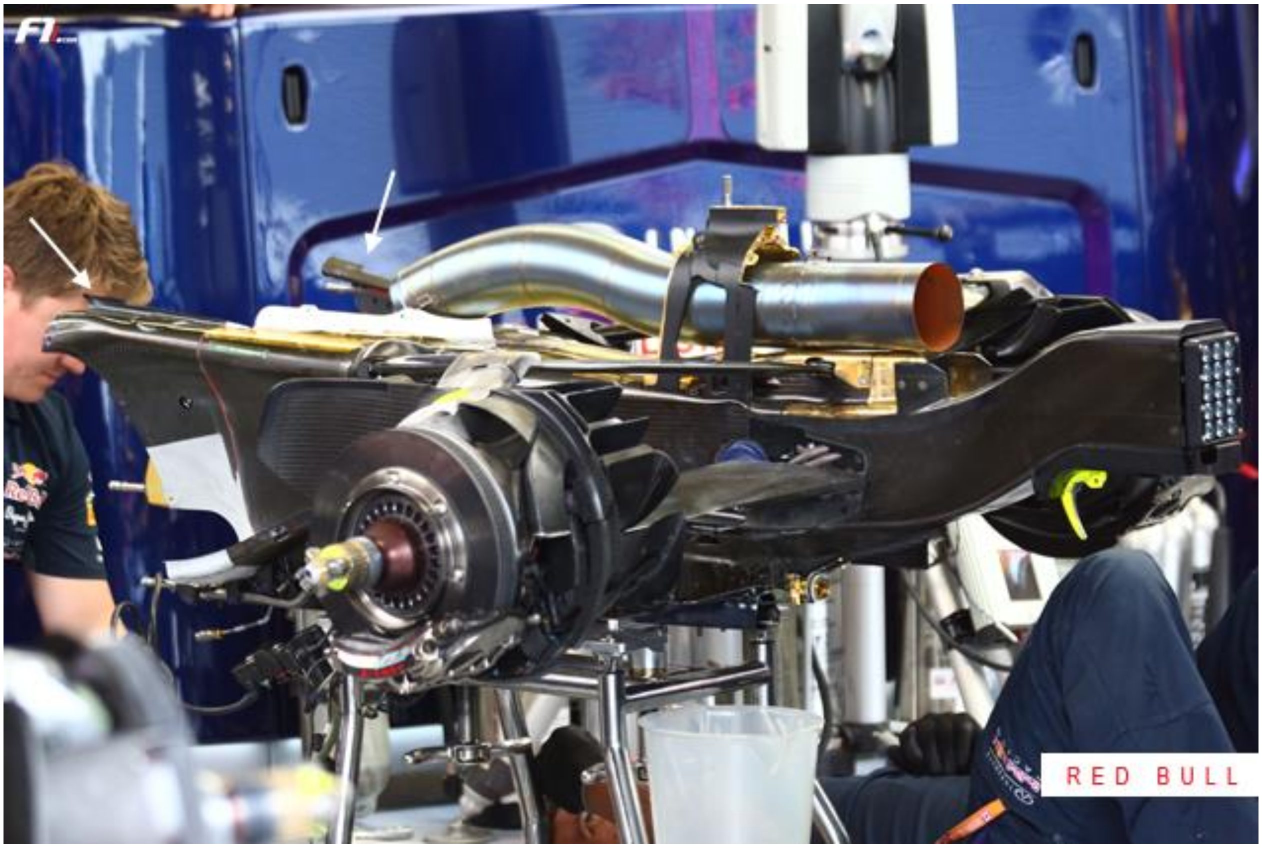
The latter has been revamped and is now shorter and more compact compared to last year's exhaust pipe. The gear case, which also fits the turbine, has been redesigned as well: its flared lower part is now enclosed and thus more rigid.

The gear case includes many elements: the turbine, part of the manifold, the collector and part of the single exhaust

Ferrari's gearbox case includes many elements: the turbine, part of the manifold, the collector and part of the single exhaust. In order to protect these and other key components – the clutch, the shafts, the torsion bars, etc. – from the heat, the inside of the case has been covered with insulating material.

The entire assembly is now stiffer with a lower centre of gravity and features less twisted pipework, which in turn increases the power released by the ICE. The new design also improves internal airflow circulation, while the tighter rear end leads to better aerodynamics in a vital area of the car.





THAT'S A WRAP

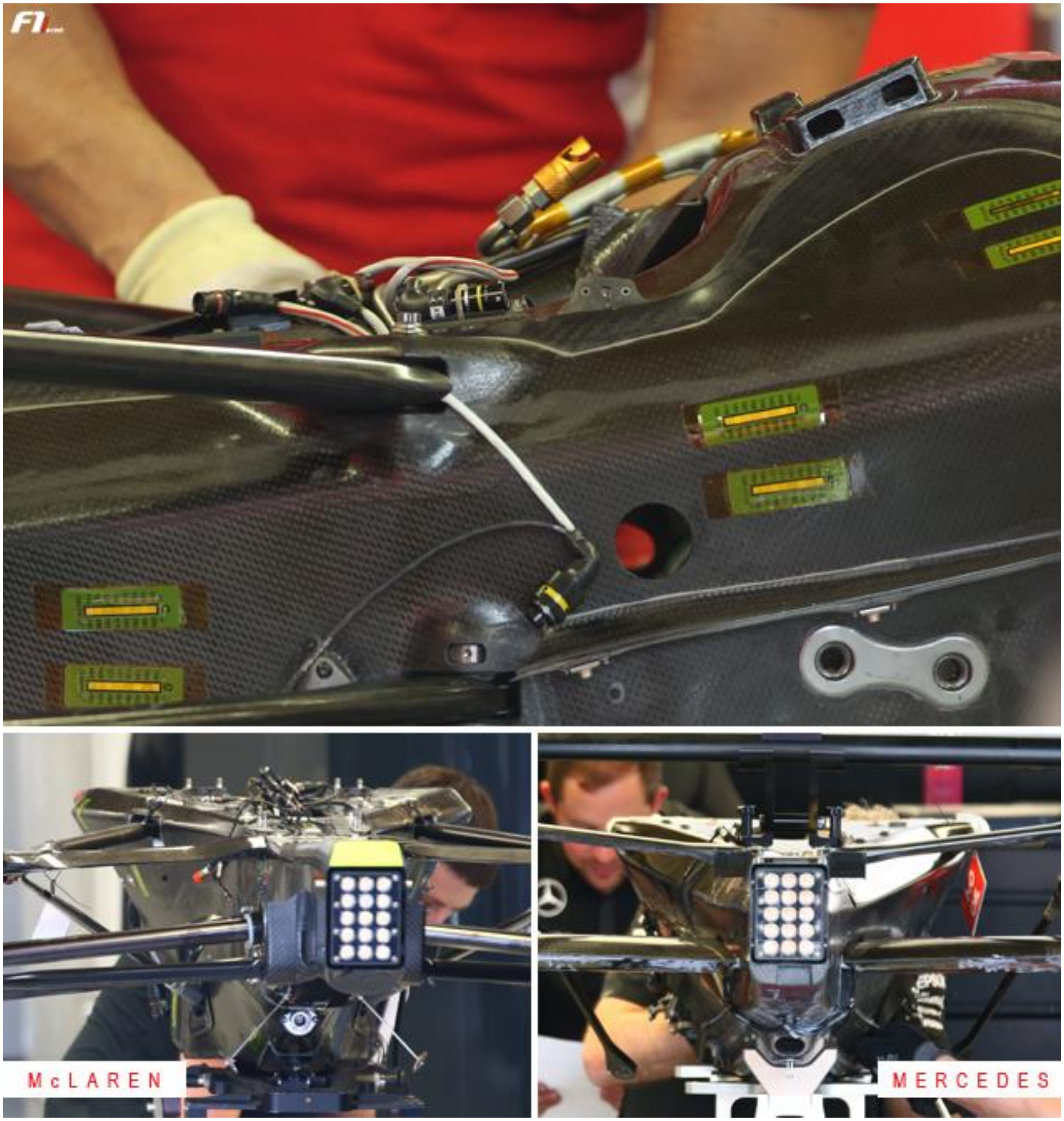
For aerodynamic purposes, F1 teams have kept the same wheelbase dimensions they had before the new radical hybrid power units were introduced into the sport.

Due to the 100kg restriction on fuel consumption, the current generation of V6s and their tank are smaller than their V8 counterparts. So engineers and designers had to make the case longer in order to have a similar wheelbase length. This size increase has freed some space in the housing since the gearbox itself has kept the same dimensions. Part of this extra space is now occupied by the turbine, which sits behinds the internal combustion engine.

Aucune écurie ne pourra copier Ferrari avant l'année prochaine
Ferrari's concept cannot be copied until at least next year

And this is the area where the new SF15-T stands out from its rivals. As one can see on the Red Bull's installation above, as well as on the McLaren's and Mercedes' assemblies below, other gear cases have an open U shape and leave some space for the turbine and exhaust. On the other hand, Ferrari's layout encapsulates both elements thanks to a closed, O-shaped design.

And no other team will be able to copy Ferrari's idea until next year for they would need to come up with a brand new gearbox. Maybe Ferrari's creativity won't prove enough to reel in Mercedes, but at least it shows the Italian squad gears up to cut the gap to the defending champions.



7.2 THE HONDA POWER UNIT 2015

7.2.1 The RA615H

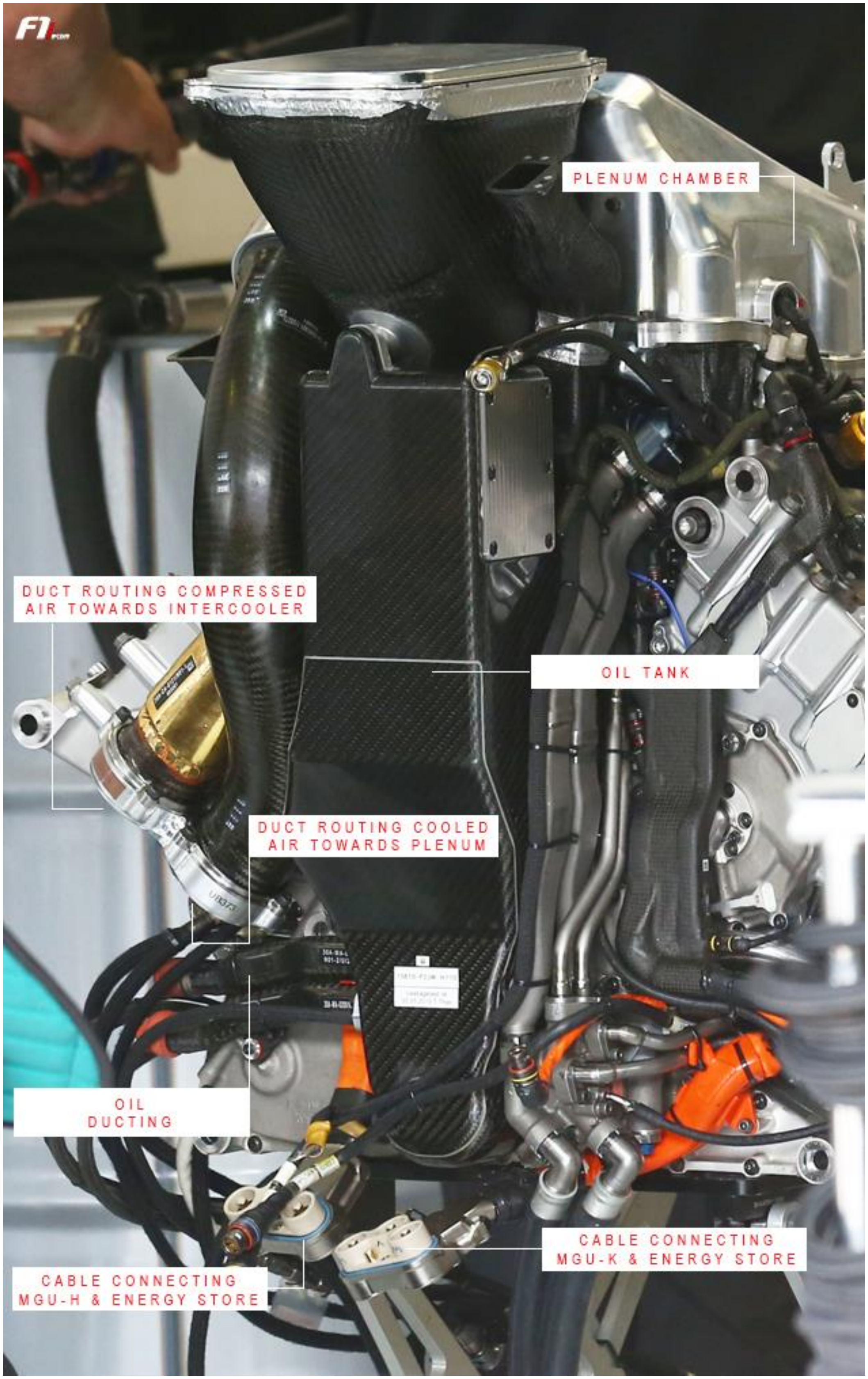
FOLLOWING IN MERCEDES' FOOTSTEPS

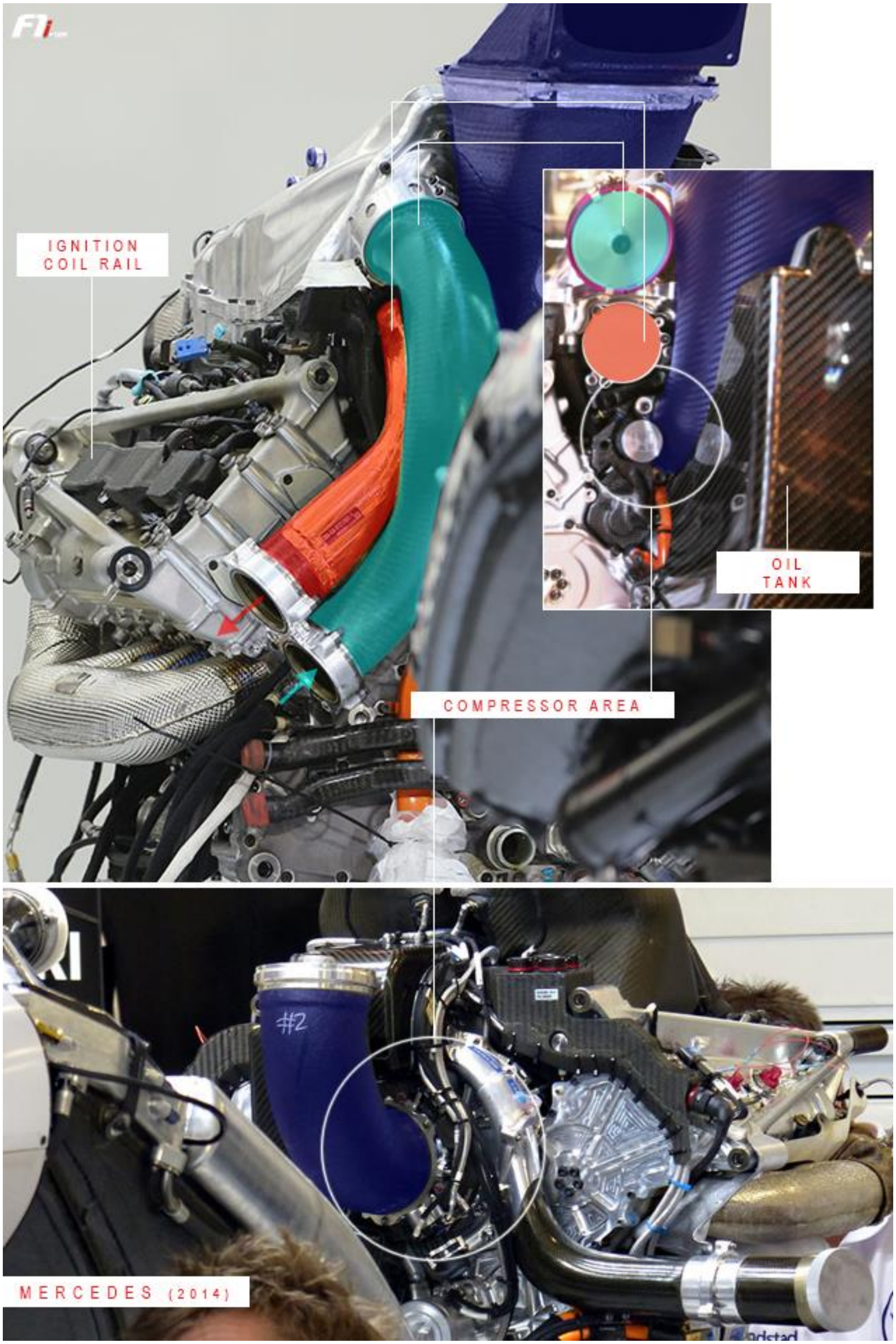
On the image next page, one can see, positioned behind the elongated oil tank, a carbon duct (here sealed with an aluminium lid). Its purpose is to channel the airflow entering the air intake hole – located right behind the driver's helmet – towards the compressor, which sits at the heart of the Japanese engine. In order to declutter its power unit installation to the maximum, Honda has split the compressor and the turbine like benchmark Mercedes, albeit in a different way.

On the dominant PU106B, the compressor - which is quite large - is placed at the front. On the RA615H, the same component sits within the vee of the engine – in between the two cylinder banks. Trying to fit a bulky element in such a tight space is no easy feat, and forced Honda engineers working at Sakura's research centre to design an exceptionally compact centrifugal rotor (we initially believed they had gone for an axial compressor), also bearing in mind that airflow exits perpendicularly to its rotational axis.

Consequently, Honda's compressor seems to be roughly a third of the size of its Mercedes counterpart (see picture below).

Unlike Renault and Ferrari, the Japanese compressor is not mounted at the back of the engine, as also highlighted by the positioning of the pipework. The red-coloured duct (covered by an insulating blanket) channels the hot and compressed air towards the intercooler, while the blue tube feeds cooling air to the inlet plenum.


PLENUM CHAMBER
DUCT ROUTING COMPRESSED AIR TOWARDS INTERCOOLER
OIL TANK
DUCT ROUTING COOLED AIR TOWARDS PLENUM
OIL DUCTING
CABLE CONNECTING MGU-K & ENERGY STORE
CABLE CONNECTING MGU-H & ENERGY STORE


IGNITION
COIL RAIL
OIL
TANK
COMPRESSOR AREA
#2
MERCEDES (2014)

GOING ONE STEP TO COMPACT?

Honda's turbine is equally compact and mounted at the back of the power unit (see on the image above). Actually, it also sits within the vee of the engine. This radical downsizing and the associated restraints were decided and agreed upon with McLaren ahead of the partners' reunion.

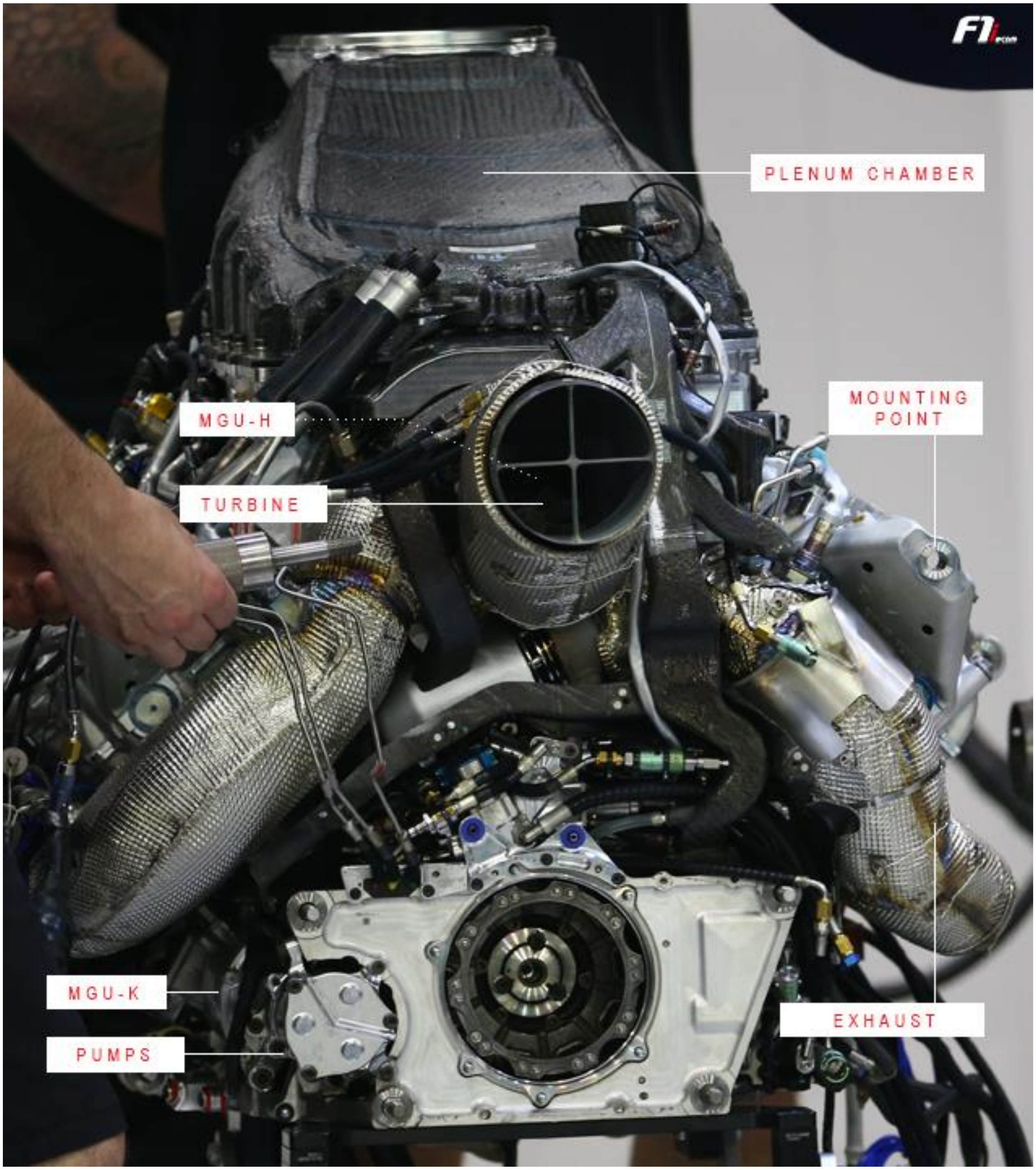
But when spinning at the same rotational speed, a smaller turbine will de facto generate less power and more back pressure, which ends up penalising the internal combustion engine (ICE) in the higher RPMs. As a result, the MGU-H absorbs less power from the turbine shaft.

"Our biggest issue is that we can't fully use our electric power," McLaren-Honda racing manager Eric Boullier recently told **F1i**. "We can't deploy it as often as our rivals. Compared to the other power units, our MGU-H is not capable of charging the battery and supplementing the MGU-K.

"According to the technical regulations, the maximum energy used by the battery to power the MGU-K is limited to 4MJ. The thing is, we use these 4MJ before finishing the lap, so can't deploy any further energy thereafter. At Spa-Francorchamps for instance, Fernando [Alonso] and Jenson [Button] could use the ERS on only one of the two big straights, and even then, not all the time."

This situation does share similarities with what Ferrari experienced last year on its own power unit. Eager to maximise aerodynamics and have a tight rear end on its F14 T, the Scuderia also ran a very compact turbocharger installation. But it ended up compromising outright turbine efficiency. Realising that aero gains did not make up for the lack of engine power, engineers at Maranello successfully made amends for 2015.

"Ferrari had pretty much the same issue as us last year," confirmed Boullier. "Their leap in performance comes from their MGU-H now working to its fullest potential."


PLENUM CHAMBER
MOUNTING POINT
MGU-H
TURBINE
MGU-K
PUMPS
EXHAUST

NO MAJOR LAYOUT CHANGE PLANNED FOR 2016

Honda had originally planned on offsetting the small size of its turbocharger by a higher rotational speed (well above the usual 12,000rpm, according to Mark Hughes). The initial idea was to draw less air but more quickly in order to have the same power output.

But the Japanese manufacturer has never managed to pull this off without encountering any reliability and overheating issues. These woes would even be compounded by Honda's MGU-H apparently sitting right next to the red-hot turbine. In an effort to improve reliability, Honda would thus be forced to lower the turbocharger's rotational speed. This would in turn limit air compression, curb ICE power, and reduce the amount of energy that can be absorbed from the turbine.

The initial idea was to draw less air but more quickly in order to have the same power output.

In order to fix the issue, there are two main possible solutions. The first option is to keep the same power unit architecture and make the downsized turbocharger design work. That would entail finally reaching the required higher rotational speeds, something Honda has failed to accomplish so far…

Despite the current reality, Honda motorsport boss Yasuhisa Arai recently said that this ambitious endeavour remained his favoured choice for 2016.

"Looking at this year and next year, we've already gone in to a plan on how to make it better based on the current layout," Arai told **F1i**, speaking via a translator. "The final plan may come in winter but we are already on it.

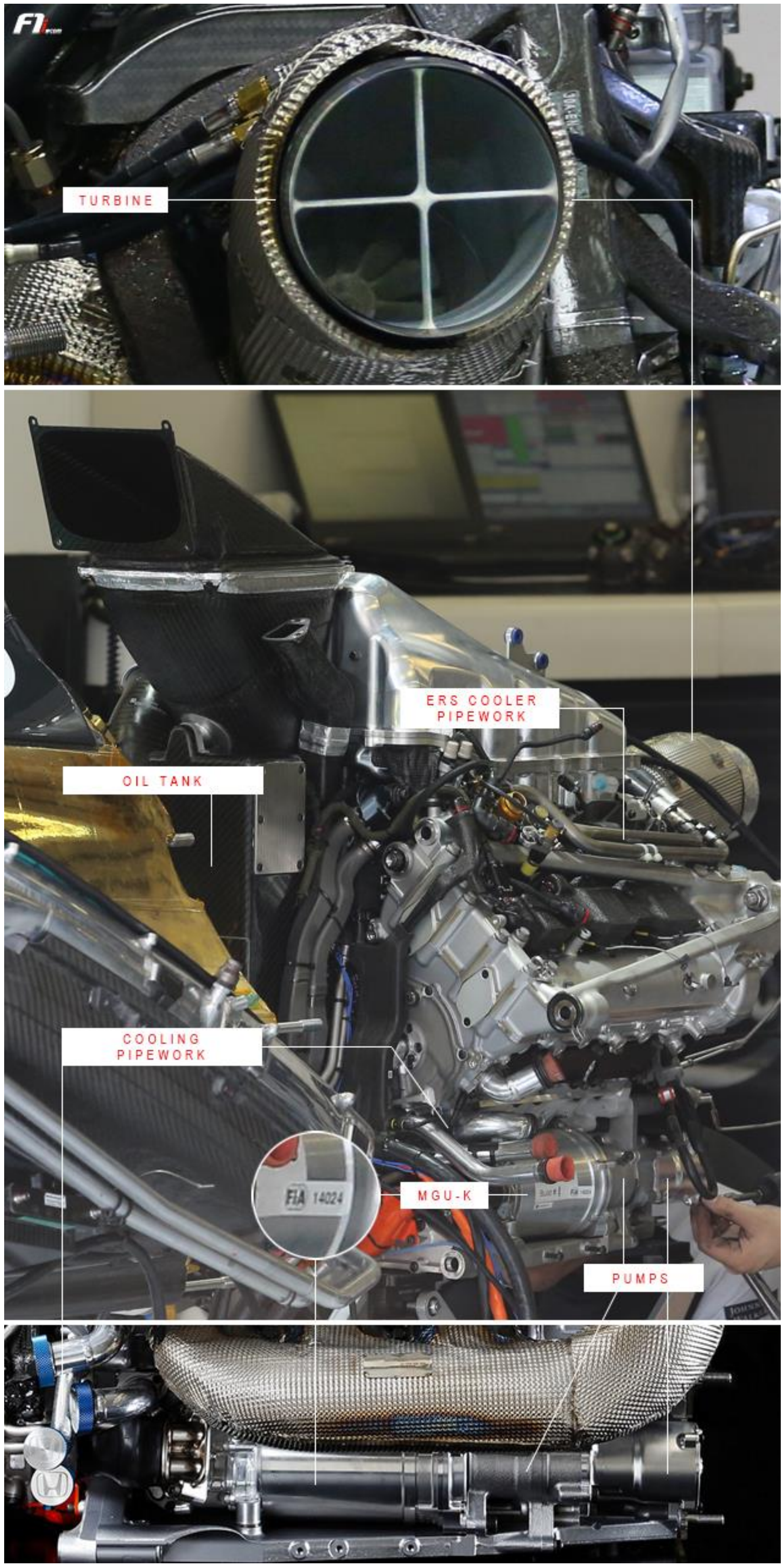
"It will be the base we work from because it's the layout we've worked on from scratch with McLaren. We think there's the possibility there, that's why we fixed on that layout. So there is more potential to be had."

The second possible option would be to increase the size of the turbocharger in order to boost engine power, although things are not that simple, nor automatic*. Plus it would go against McLaren chairman Ron Dennis' "size zero" design philosophy.

In both cases, engineers at Sakura will have to thoroughly develop their power unit ahead of next year, which means spending many of their 32 tokens allocated for 2016. Will they be able to make Ferrari-like strides in one winter? Such a feat would probably require poaching top personnel away from its rivals, an option rejected by Honda, which could hire consultants instead, as suggested by Eric Boullier to **F1i**.

Looking at the bottom of the picture, one can spot the engine water and oil coolers, the MGU-K (which must be homologated by the FIA, hence the sticker) and, on the same shaft, what probably are the pressure and drain pumps for the crankcase.

"There is not any real proportional correlation between the size of the compressor and the power of the MGU-H," Renault Sport F1 director of operations Remi Taffin told **F1i. "Simplifying to the extreme, the level of boost pressure defines the size and workload of the compressor, which in turn will have an impact on the design of the turbine."*


TURBINE
ERS COOLER PIPEWORK
OIL TANK
COOLING PIPEWORK
MGU-K
PUMPS
FIA 14024

A TWO-WATEGATE INSTALLATION

On the image next page, one can see two wastegates (the valves that control the flow of exhaust gas going to the turbine), which are placed above and below the exhaust and included in the turbine casing. The upper wastegate can also be spotted in the circle, a zoom-in photograph that was taken at Suzuka where Honda's power unit was on display.

In the wake of revised 2016 FIA technical regulations, all engine manufacturers will need to alter the design of their single exhaust systems. In an effort to make Formula One cars louder, the sport's governing body require teams to add one or two smaller tailpipes for the wastegastes. The good news for Honda is that it will also be able to update its turbine without using any engine development tokens since the wastegates are integral elements of the device.

One can also notice that the clutch is installed above the ICE instead of the traditional gearbox-mounted design. The current turbocharged V6s have a lower rev limit (15,000 rpm), which means the clutch can be fixed to the engine. Such assembly is not new, and remains the preferable solution following the significant increase in torque compared to the previous normally aspirated V8s. Mercedes already had an identical installation on last year's PU106A.

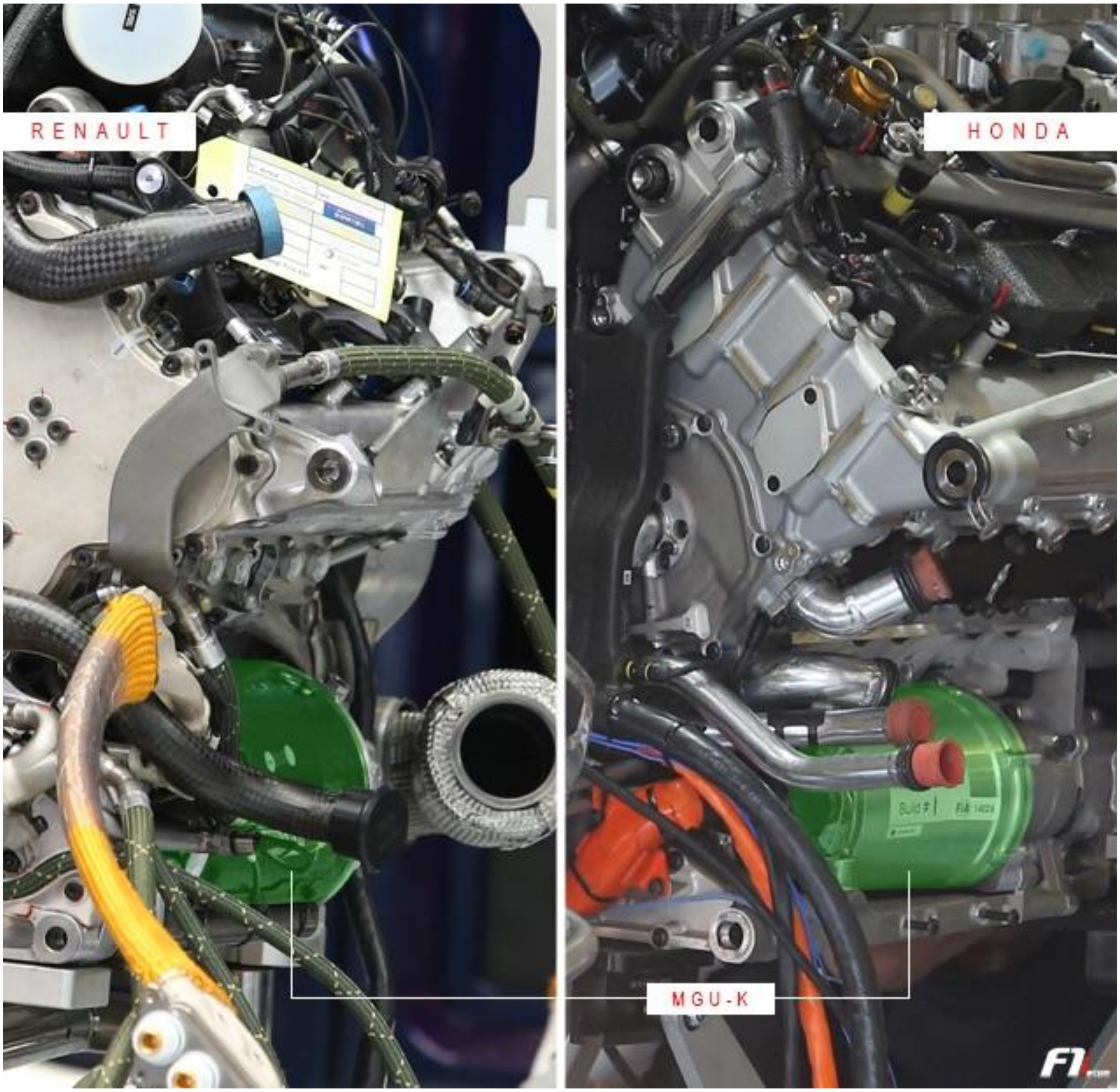

CLUTCH
PIPES
WASTEGATES
CLUTCH

DOWNSIZING ACROSS THE BOARD

This comes as little surprise: Honda's MGU-K is also very compact. As far as can be ascertained, Renault's motor-generator unit looks bulkier (compare green-coloured elements).

On the Japanese power unit, the energy recovery system is linked to the crankshaft via a series of gears that, according to some sources, would be at the back of the engine (when most of the other designs have them at the front).

Also visible is the ignition coil rail that is comprised of three coils (one for each cylinder), as well as the FIA-standard mounting points – these are identical on all power units. As a reminder, the ruling body also controls the angle of the vee (90°), the bore (80mm), the stroke (53mm), as well as the crank height (90mm).



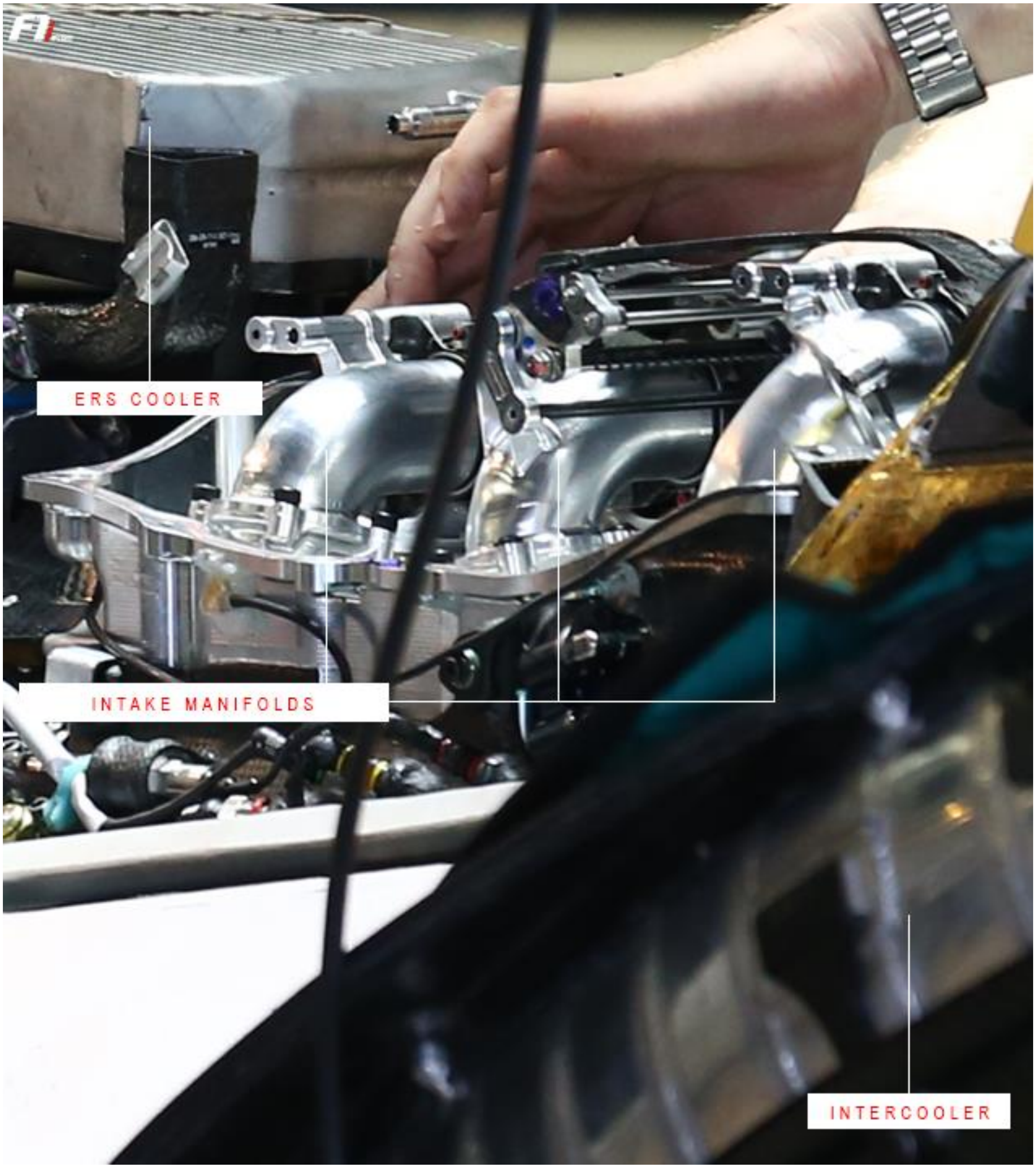
INLET PLENUM

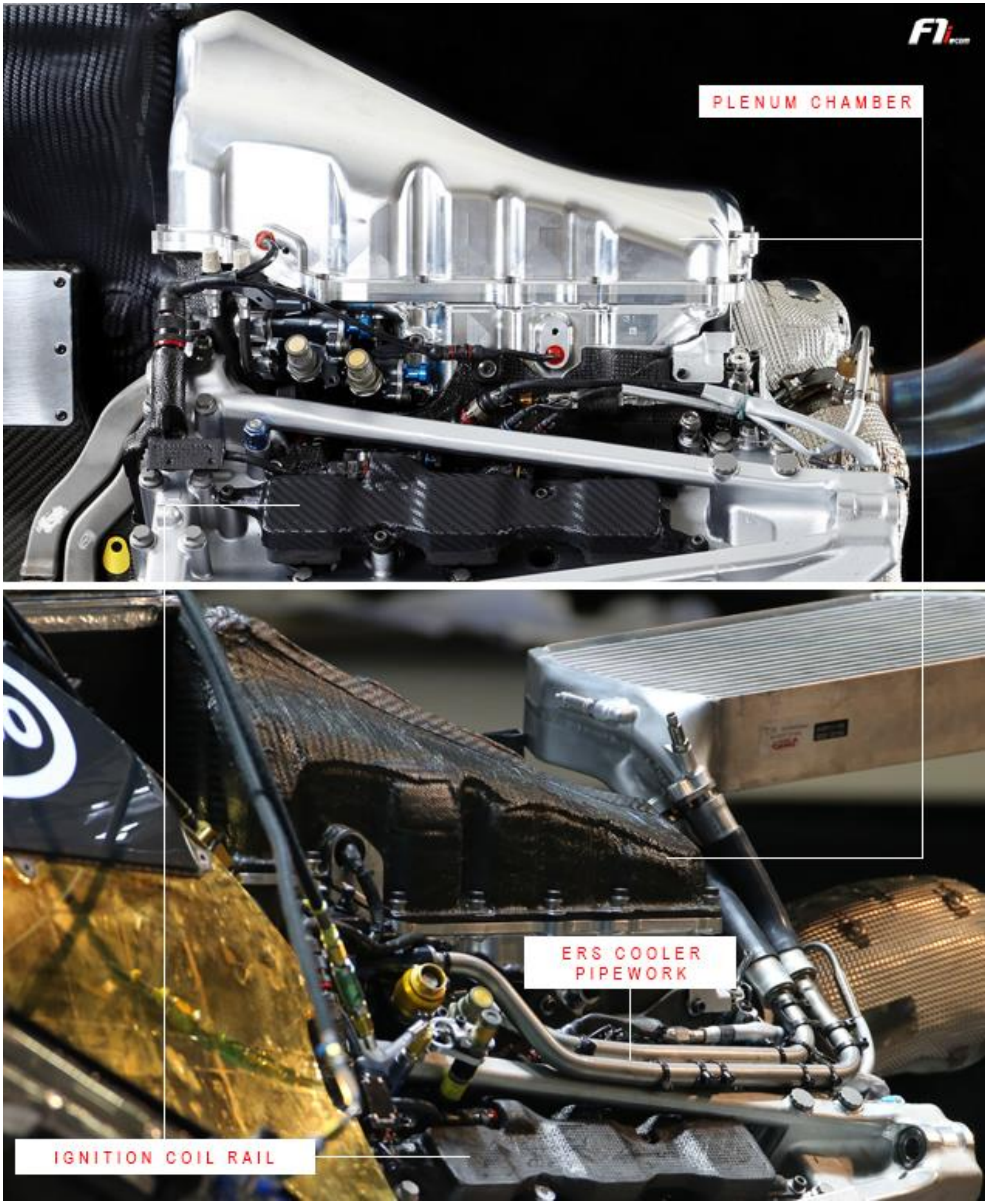
Hollowed out from the inside, the inlet plenum has a fairly low profile design.

When removed (see the image above), one can notice that the intake manifolds make a 90° bend and belong to a complex airflow-guiding system positioned ahead of the intake trumpets – which are probably variable.

These 90° curves spawn from Honda engineers' willingness to reduce as much as possible the volume of the inlet plenum. Like most of the engine, it is made out of aluminium, though a carbon-made version has also been used several times (see comparison below).

It’s worth noticing that, before entering the intake manifolds, the compressed airflow travels through an air-to-air intercooler placed inside the MP4-30’s right sidepod. Renault has a similar component, whereas Mercedes and Ferrari use an air-to-water intercooler. The only difference is that the device is lodged within the monocoque on the Silver Arrows when it sits within the vee of the ICE on the Italian power unit. Both installations share the same goal however, namely to free up sidepod space and curb internal airflow resistance.


ERS COOLER
INTAKE MANIFOLDS
INTERCOOLER


PLENUM CHAMBER
ERS COOLER PIPEWORK
IGNITION COIL RAIL

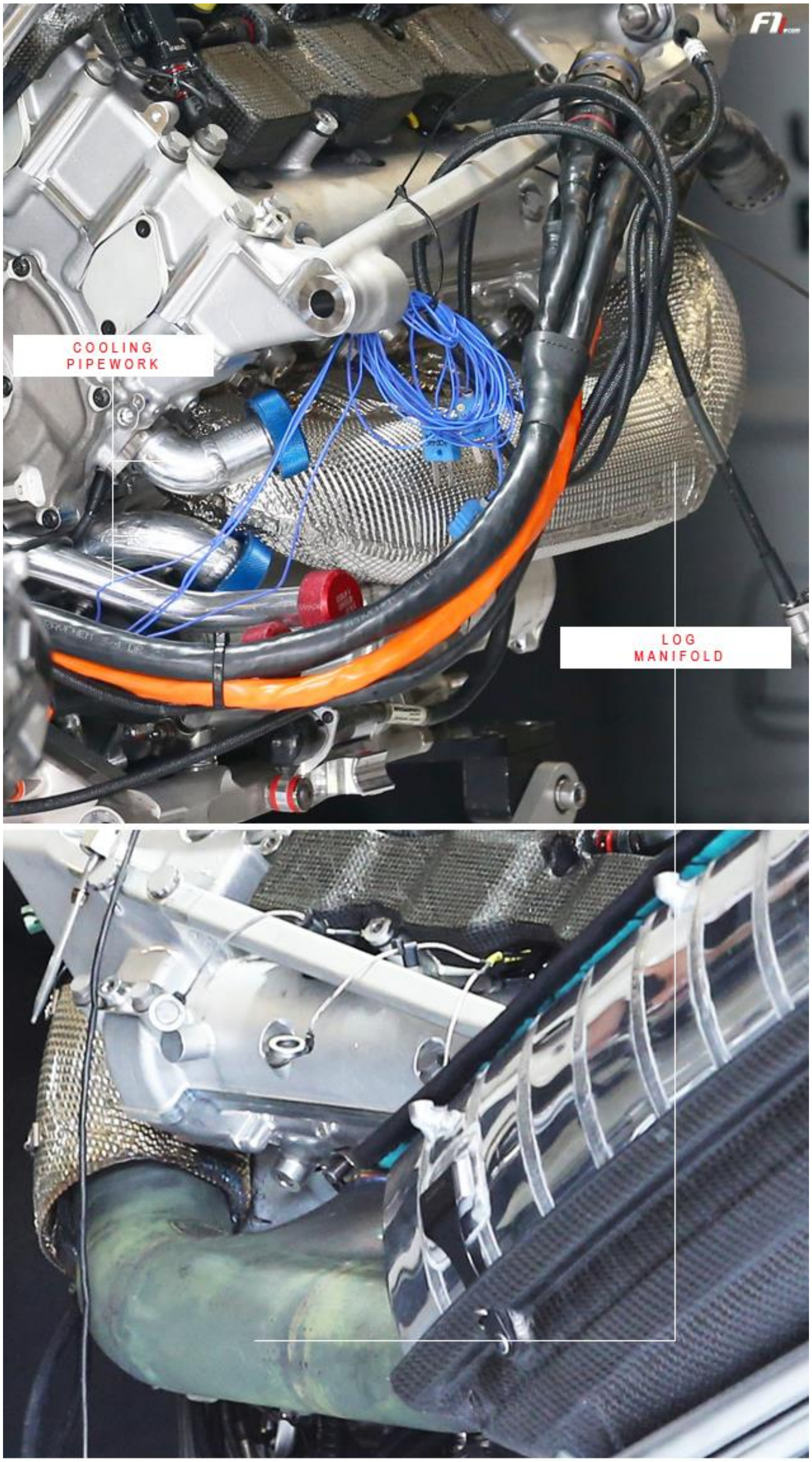
DRAWING INSPIRATION FROM LAST YEAR'S WINNING DESIGN

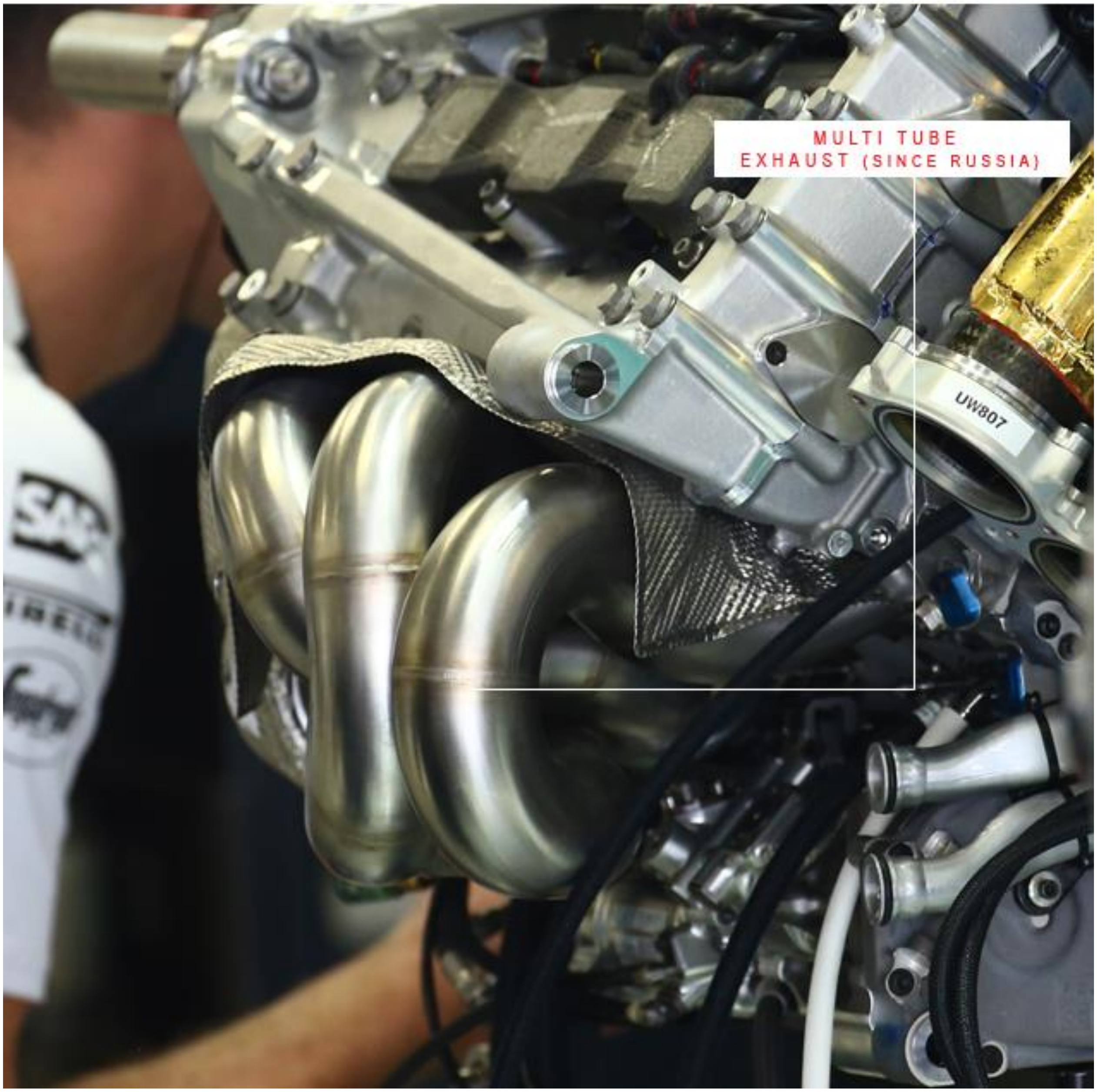
As shown on the pictures, Honda is using a log manifold in order to collect burnt gasses, but has switched to multi tube exhausts in Austin. Such design was a distinctive feature on last year's Mercedes PU106A before the world champions elected to replace it with more conventional exhaust manifolds.

The log-style exhaust is quite short, which helps prevent exhaust gasses from losing too much pressure on exit. This also means that more energy is consequently channelled towards the turbine, and then recovered by the MGU-H. However, engineers have to keep an eye for any potential collisions between the different gas molecules, which in turn might create turbulences. Last but not least, the compactness of the log manifold package shows great reliability while also giving more freedom to aerodynamicists.

Why did Mercedes elect to ditch it for 2015 then? Probably because a longer, more conventional design also has its own advantages, like offering more leeway to regulate exhaust gasses across all RPMs.

Manifolds are made of very thin metal sheets, which leads Honda and rival engine manufacturers to wrap up the exhaust pipes in some sort of insulating blanket in order to limit heat loss and foster gas expansion. On the image below, the log manifold can be seen without its thermal insulation cover.


COOLING
PIPEWORK
LOG
MANIFOLD


MULTI TUBE
EXHAUST (SINCE RUSSIA)
UW807

ALL IN THE BOX

Unlike Renault and Mercedes (at least if we base ourselves on the official pictures released), Honda uses a single unit to fit the battery as well as the control electronic boxes of both MGUs. This casing is positioned behind the driver's seat and below the tank and one can spot Thermax labels – whose colour change depending on the temperature – and FIA stickers on it.

While this compact design frees up space beneath the oil tank and helps have a tighter overall package, it also makes cooling quite tricky.

Honda has failed to exploit the theoretical advantages of its RA165H's Mercedes-like architecture.

Honda had the ambition to catch up with their rivals by using ground-breaking technologies, but these have proved to be technically immature. There lies the main reason why the RA165H has failed to exploit the theoretical advantages of its Mercedes-like architecture. The split-turbo installation should have improved cooling and the log manifold limited turbo lag, i.e. the amount of energy recovered by the energy recovery systems (ERS) and subsequently used by the MGU-H to keep the turbine spinning when the throttle pedal is not pressed.

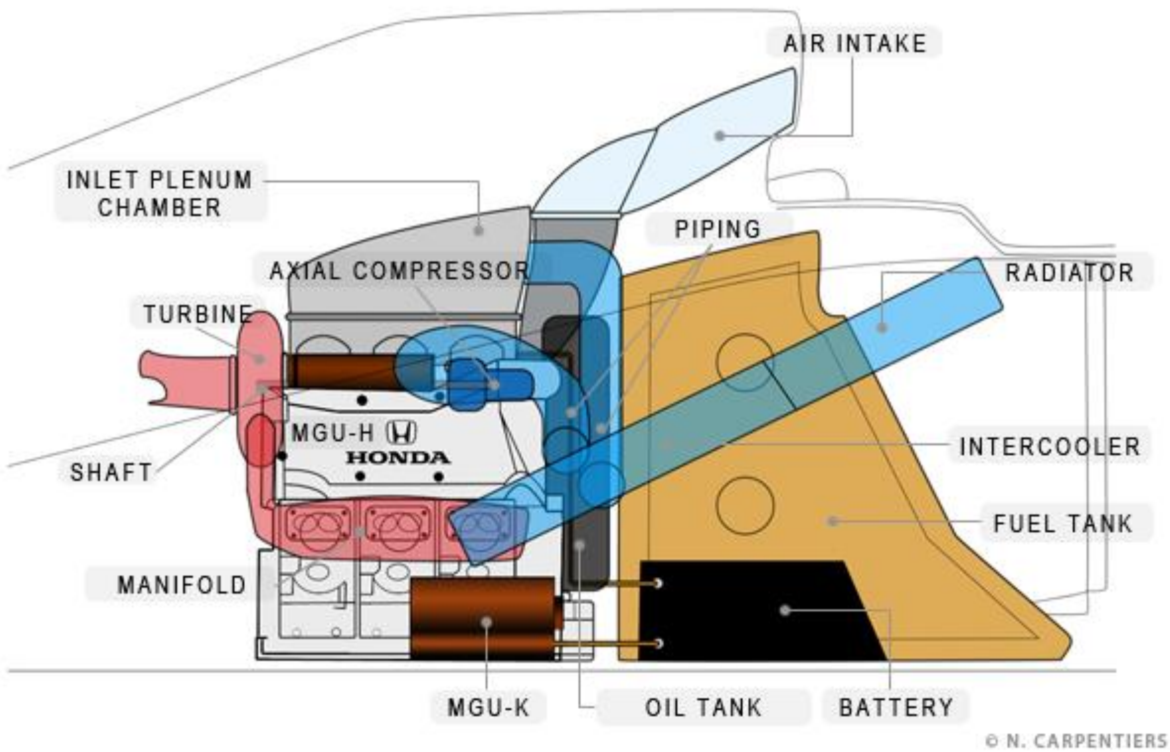
Beyond the overall power unit design, the difference lies more in how well it is implemented. And no matter how deep under the skin of the engines you can travel with exclusive images, this factor remains invisible.


F1i.com


MERCEDES


RENAULT

7.2.2 Honda's Radical Power Unit Design



Balancing tradition and modernism has always been part of the Japanese mantra and way of life. But when it comes to motor racing, the Land of the Rising Sun has constantly embraced innovation at unabated speed. With high-technology etched in the country's DNA, the Formula One circus has been quite eager to see what lies behind the new Honda hybrid power unit.

Poor reliability has been hampering McLaren's progress from the onset, but many observers have always believed these teething problems were only the result of bold technical calls made by the Japanese manufacturer. So keen was Honda to catch up with their rivals that it started using pioneering technologies… before these had been thoroughly tried and tested. Mindful of the engine development scope reducing over the next seasons, the Sakura-based giant did not want to start its 2015 campaign with a conventional, but unspectacular, turbocharged V6 power unit.

Honda's radical engine design also spawns – this might even be the No. 1 reason – from McLaren's aggressive technical specifications and "size zero" MP4-30, the brainchild of aerodynamicist Peter Prodromou. Indeed, McLaren has insisted on giving maximum freedom to Adrian Newey's former protégé at Red Bull.

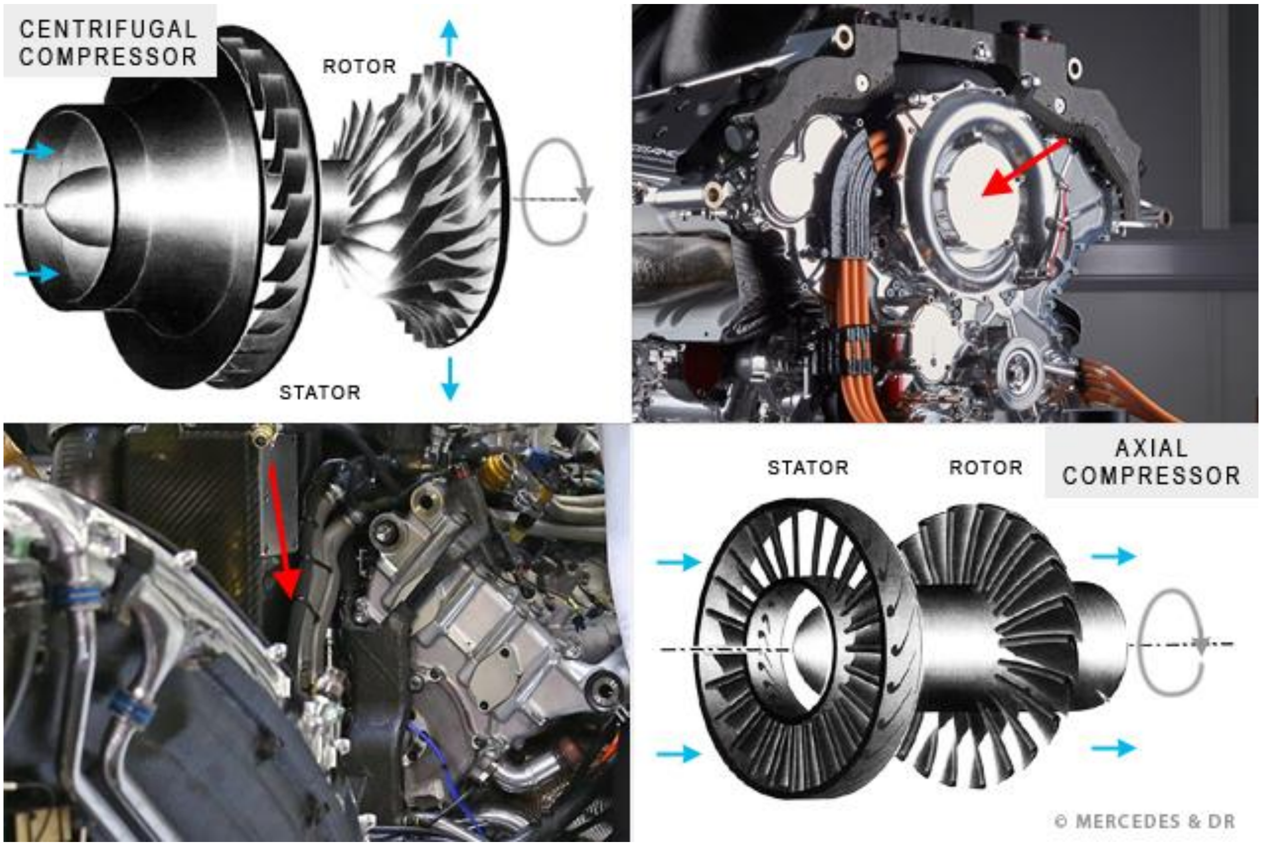
"Having the engine, its ancillaries and the ERS impede on the car's aerodynamic performance was simply not an option," said McLaren racing director Eric Boullier. "The chassis has been designed to wrap up so compactly at the rear that we had to include all elements into a tight package with nothing sticking out. In order to achieve this, Honda actually had to make several attempts and come up with three versions of the power unit because the initial two did not meet the chassis/aero technical specifications. It took them a lot of effort."

AN AXIAL COMPRESSOR FOR A RADICAL DESIGN

In order to declutter its PU installation, Honda has followed in the footsteps of Mercedes and split the compressor and the turbine, albeit in a different way compared to the current benchmark. As detailed by *Autosport*'s Craig Scarborough, the Japanese constructor has pushed the 'minimal volume' concept even further on its RA615H. The compressor has actually been placed within the Vee of the engine – in between the two cylinder banks – and alongside the MGU-H. A clever solution indeed, but how do you make it work?

Lodging a compressor in such a tight place has led the engineers at Sakura to opt for an axial compressor instead of a centrifugal rotor. What's the difference? An axial compressor sees the airflow go through transversally, along the rotational axis. This allows the mechanical component to have an elongated shape, which in turn helps save space but does require a more twisted pipework system. On the other hand, the centrifugal design channels the airflow perpendicularly to its rotational axis, hence its bigger dimensions.

Although the axial compressor has a faster rotational speed – which improves engine and MGU-H operation –, it is harder to reach the same compression ratio as its centrifugal counterpart. Indeed, Article 5.1.6 of this year's FIA technical regulations reads that "pressure charging may only be effected by the use of a sole single stage compressor linked to a sole single stage exhaust turbine by a shaft assembly parallel to the engine crankshaft". However, this setback is partially offset by the 100kg/hr restriction on fuel flow (typical maximum boost pressure is around 3.5 bar abs in these conditions). Meanwhile, the turbine has a more conventional positioning, i.e. behind the engine.

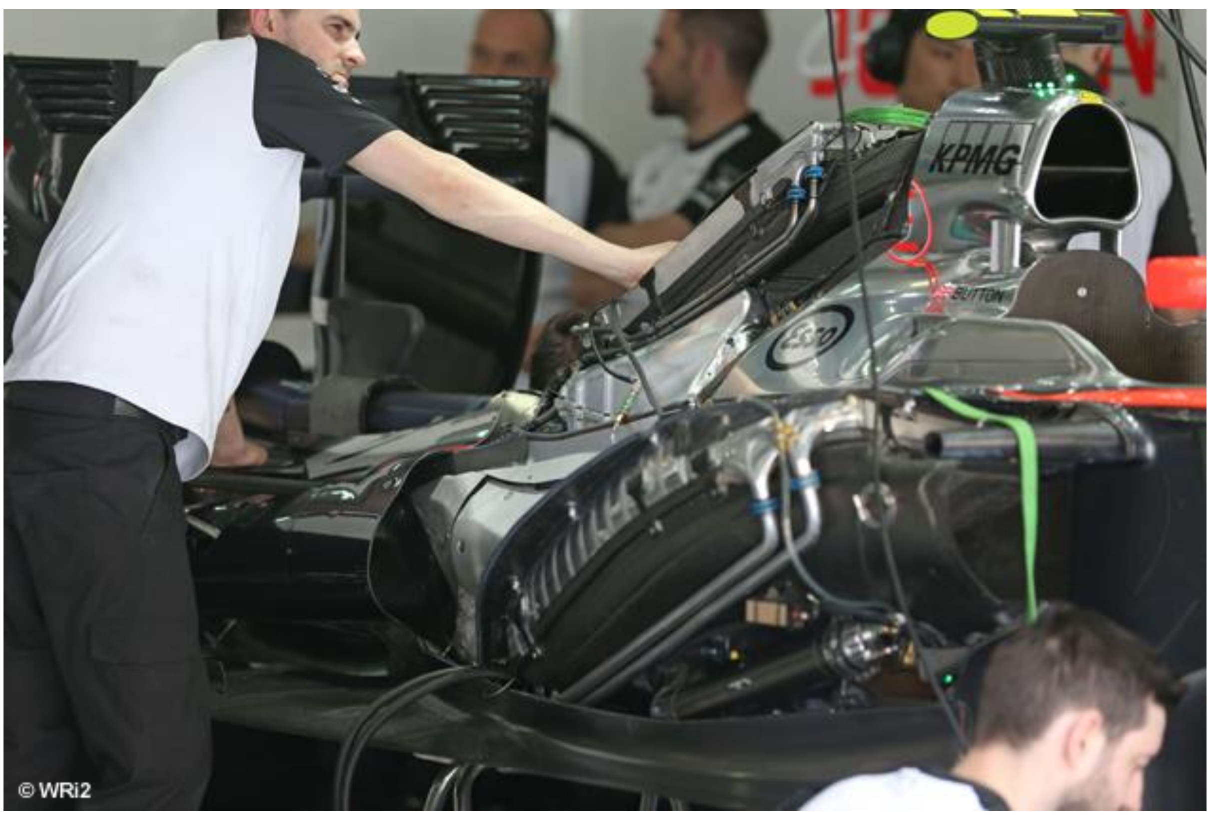

CENTRIFUGAL COMPRESSOR
ROTOR
STATOR
STATOR
ROTOR
AXIAL COMPRESSOR
© MERCEDES & DR

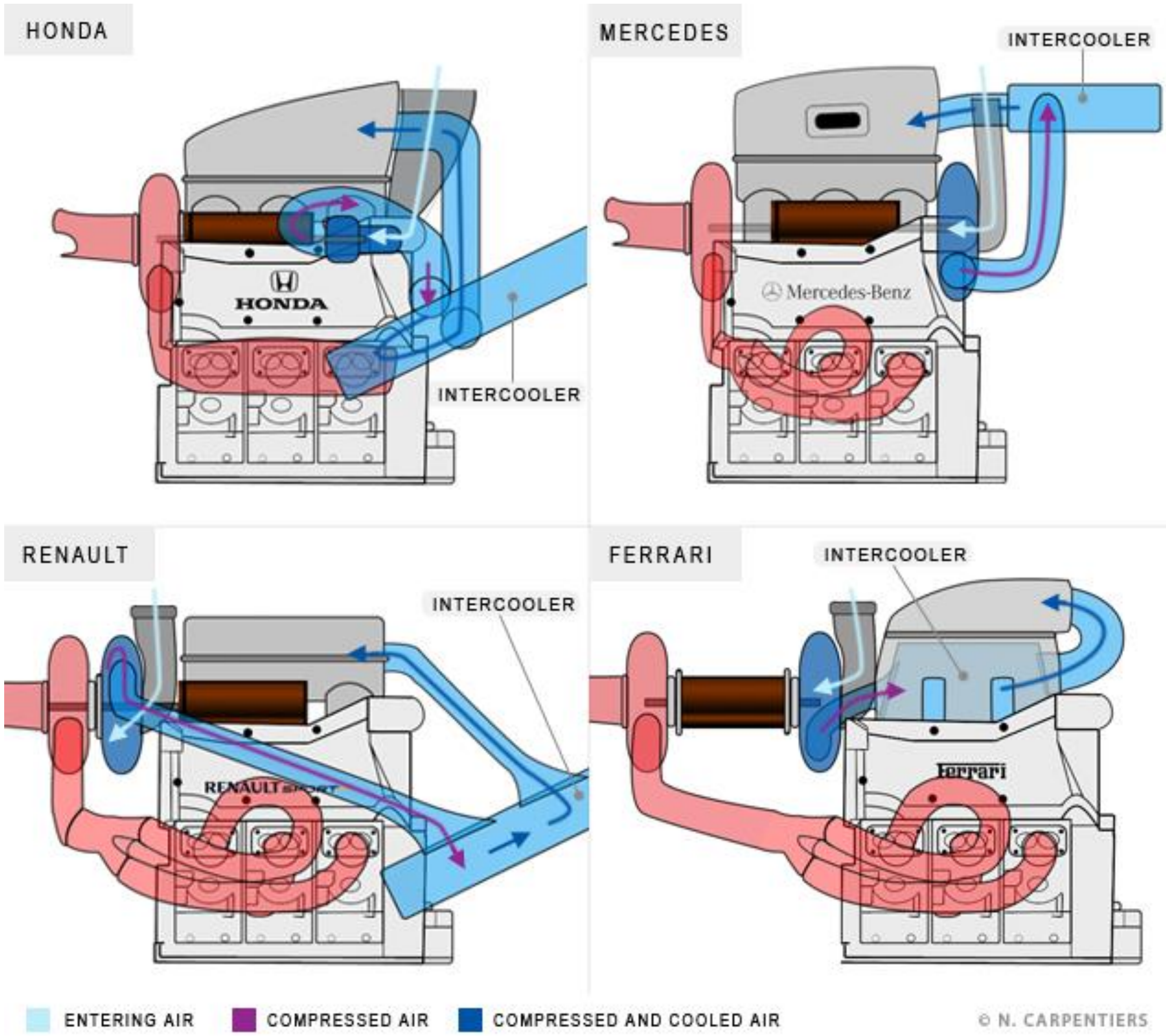
THE IMPORTANCE OF BEING COMPACT

As shown on the illustrations below, Honda's V6 engine installation is quite close to Mercedes' implementation, but there are definitely several differences.

First of all, the RA615H's axial compressor allows a tighter overall package than on the PU106B Hybrid, which features a centrifugal rotor. As a result, the Japanese power unit needs very specific pipework. Another difference comes from the MGU-H's cooling requirements since the motor generator sits in a tight space, i.e. within the Vee of the engine and alongside the axial compressor. In order to recover energy from the exhaust, Honda has elected to go for the log manifold design… which was one of the key features on last year's Mercedes PU106A! For this season, the German behemoth has decided to switch to a more conventional manifold design. Theoretically, the shorter log manifold solution enables constructors to have a tighter package as well as allowing for more energy to be fed towards the turbine.

However, there are also similarities between the Honda hybrid unit and the Mercedes power plant. The split turbo installation benefits cooling since the compressor and the associated ducts are placed in front of the engine, namely far from the 900°C heat released by the turbine and the red-hot exhausts. With the compressed air needing less cooling, the whole assembly enables teams to use a smaller intercooler (compared for instance to the Renault Energy F1-2015 where the compressor and turbine are implemented together).

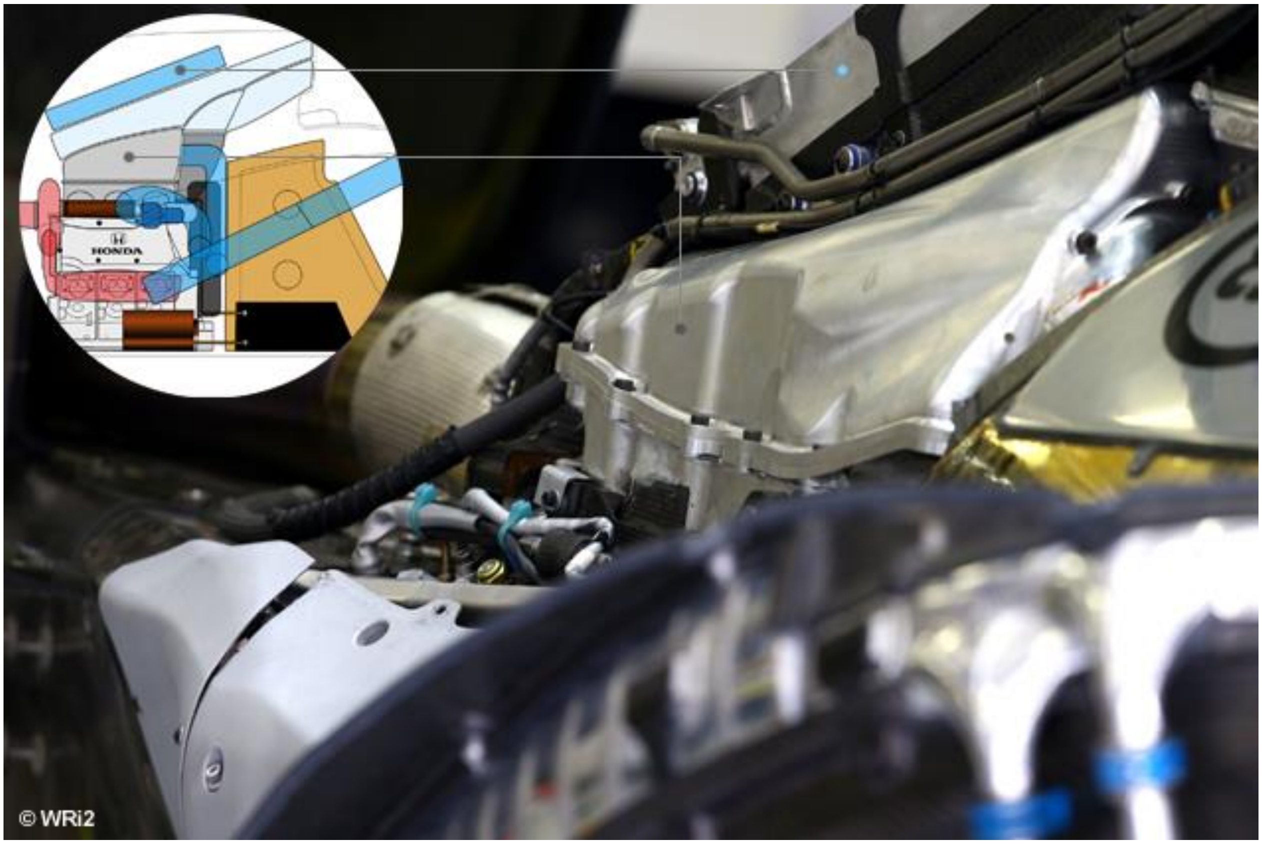




Speaking of intercooler, Mercedes, Honda, and Ferrari all have a different installations on their respective power unit. The W06 Hybrid's intercooler has a central positioning and is lodged directly within the monocoque, while the Honda-powered MP4-30 has a more traditional design with the intercooler placed in the car's right sidepod. On the Ferrari power unit*, the same component sits within the two cylinder banks in order to limit airflow resistance in the sidepods.

Another advantage of Mercedes' and Honda's split installation is the shorter pipework between the compressor and the intercooler. Therefore, the compressed air needs less time and less energy to circulate, which in turn helps reduce the turbo lag phenomenon. This also means that a greater part of the energy recovered by the ERS can be used for the actual boost, as the MGU-H feeds less energy towards the turbine when the driver is not on the throttle.

Note: **This year's Ferrari 059/4 has still its turbocharger placed at the back of the engine (just like Renault's Energy F1-2015) and its slightly revised intercooler within the two rows of cylinders. However, it remains unclear whether the MGU-H still sits in between the compressor and the turbine.*



NOVELTIES ACROSS THE BOARD

Above the V6 engine, the car's air intake is split into a pair of ducts. The first duct feeds cooling air to a big radiator – actually an ERS cooler – that is attached directly to it. Hot air coming off this element then flows along the curve of the engine cover, down towards an oversized flared vent at the rear.

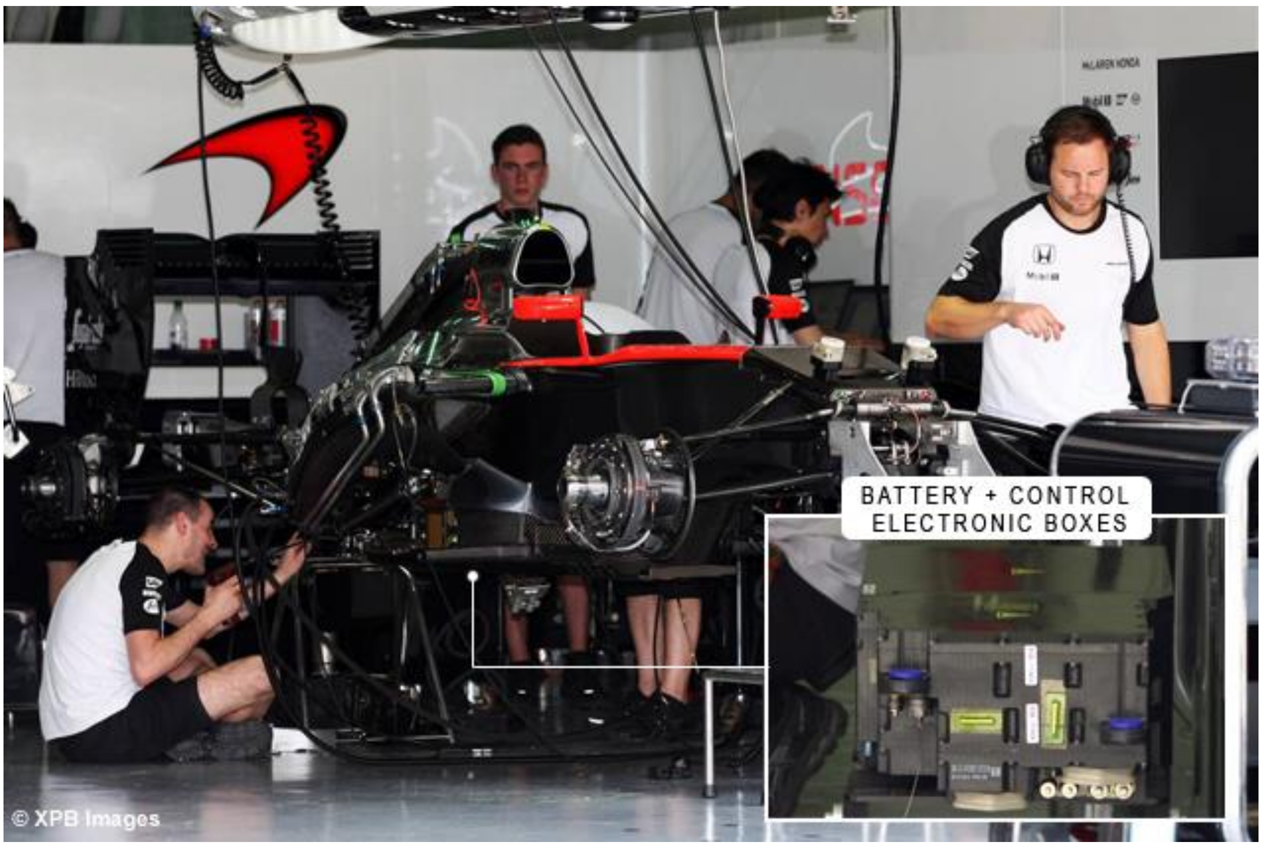
The second duct is more conventional and feeds air to the internal combustion engine via the compressor and the inlet plenum chamber. The latter is made of aluminium and sits quite low, as the inlet variable trumpets are oriented at 90 degrees and thus direct the cooling air perpendicularly towards the cylinders.

Once Honda gets on top of its current reliability woes, there is no doubt McLaren will be able to make the most of its "zero size" MP4-30. But the clock is ticking...

Another originality is the single unit that fits the battery as well as the control electronic boxes of both MGUs (see below). This compact design most certainly frees up space beneath the oil tank and helps have a tighter overall package, but it also makes cooling quite tricky.

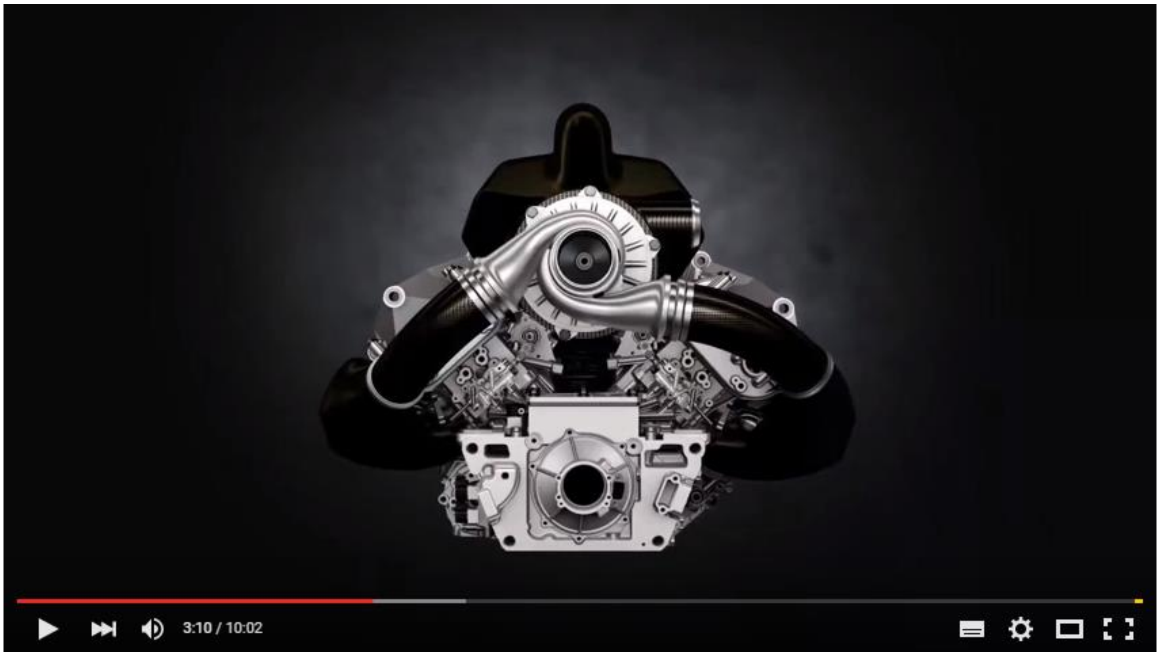
And with both motor-generator units absolutely requiring water or oil cooling, Honda has so far been forced to downtune its power unit in order to avoid any overheating issues or any leaks in the cooling system because of faulty seals. The MGU-K and oil tank have a more conventional positioning, respectively in front of the engine and beneath the left cylinder bank.

Once Honda gets on top of its current reliability woes, there is no doubt McLaren will be able to make the most of its “zero size” MP4-30. Meanwhile, the renewed alliance will need to show *gaman* (resilience in Japanese) and bide its time. “Fall seven times, stand up eight” says a popular proverb in the Land of the Rising Sun.



NB: All the drawings in this feature have been made with a view to offering informative comparisons to the readers. Therefore, these are simplified, easy-to-digest illustrations of the complex F1 power units.

7.2.3 Video – 2015 Honda F1 Engine by Craig Scarborough



7.3 THE MERCEDES POWER UNIT 2015

[Source: http://www.f1i.com – Nicolas Carpentiers]

7.3.1 The PU106A

HARMONIOUS COMPLEXITY

Ever since the introduction in Formula One of the hybrid turbocharged power units in 2014, Mercedes has been occupying centre stage, leaving rival engine manufacturers in its shadow. In two seasons, the German behemoth has claimed 32 wins and 37 pole positions (36 for its works outfit and one for customer team Williams) out of 38 grand prix weekends. That's total dominance for you.

Under the stewardship of Mercedes power unit boss Andy Cowell, engine engineers working at High Performance Powertrains (HPP) have come up with a clever and efficient design where every component – turbocharged V6 engine, MGU-K and MGU-H, battery, etc. – work in a seamless manner.

"The engine and the ERS are so interlinked, we are constantly debating [where to develop next]," Cowell told*Autosport*. "Should we increase the crank power, or should we increase the amount of power that we take out of the MGU-H and put into the battery, or to power the MGU-K, because of the flexibility of different energy flows that you've got there?

CHASING ACROSS-THE-BOARD EFFICIENCY

"All the work around combustion efficiency is very potent, because you've got 1240KW potential in the fuel with it flowing at 100kg/h, so the day we get to 100 per cent conversion efficiency, we will have 1240KW as well as the K. That's our aspiration before we retire.

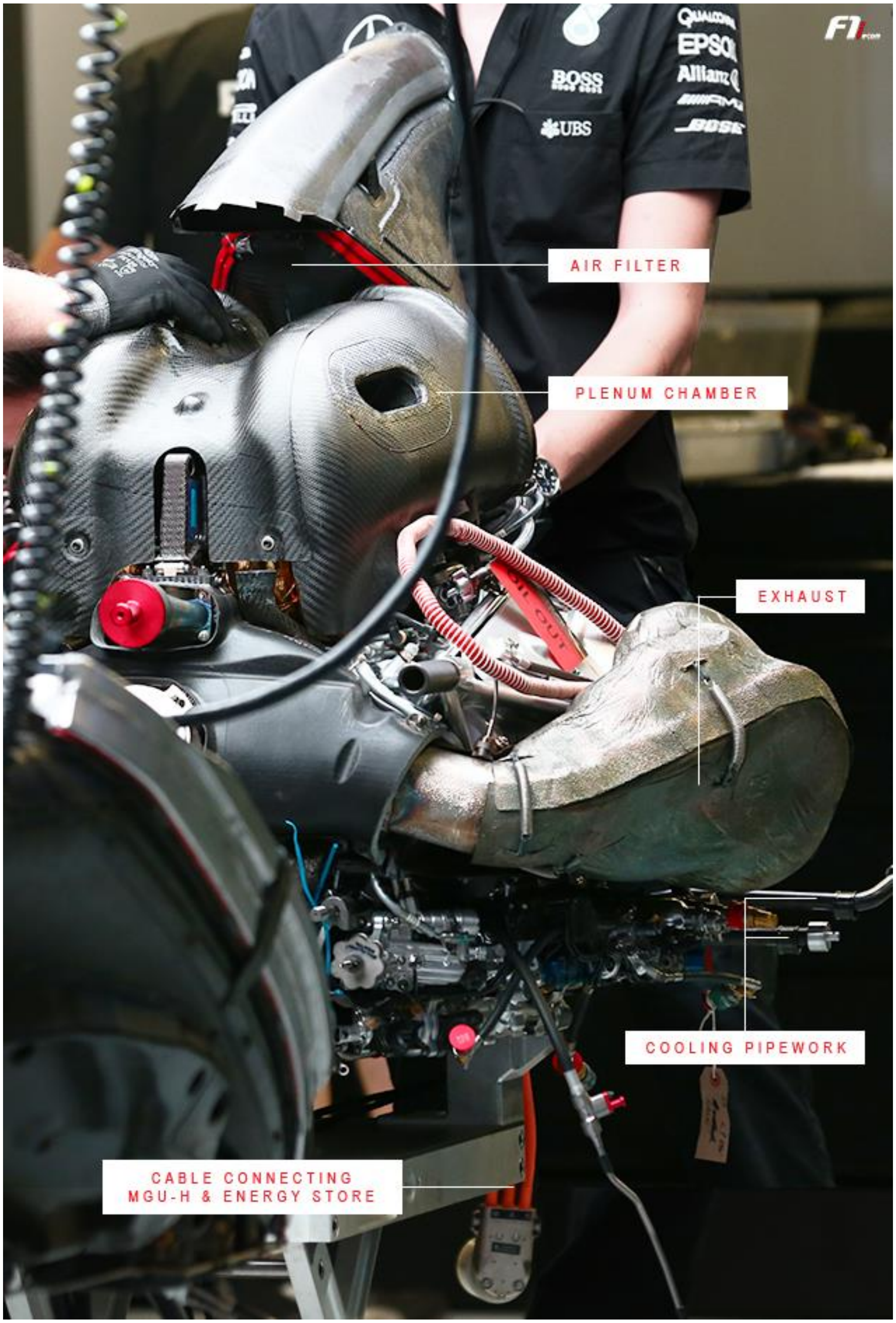
"There are losses, though. There is still some energy in the exhaust as it goes through the turbine, so we are chasing turbine efficiency; we are chasing H efficiency, we are chasing cable efficiency - the orange cables, the connectors, the cable sizes - that sort of technology.

"We are chasing the high-powered switching efficiency and then the same on the K. And when we store the energy in the battery we are making sure we are not losing a lot of energy there. So all of that really matters, and a lot of the ERS aspect provides tactical opportunity.

"The straight thermal efficiency in the ICE [combustion engine] - that's good old fashioned crank grunt. The combustion chamber and the journey of the air in, and the fuel injection, and the chemistry, and the exhaust system, and its interaction with the turbine - there are many components, many parameters that you are chasing to improve.

"All of those have improved together. One of the bits on its own wouldn't deliver anything, but that bit with the rest has delivered something. It's all beautifully interlinked – the fuel and the combustion process and the task of liberating useful power from this chemical energy."

Mercedes' engine dominance spawns from Brixworth's potent brainpower, but also from its technological edge and early start, with Cowell's team beginning to work on their hybrid power unit back in 2010. And they have gone for a very specific engine architecture, which remains a distinctive feature to this date.

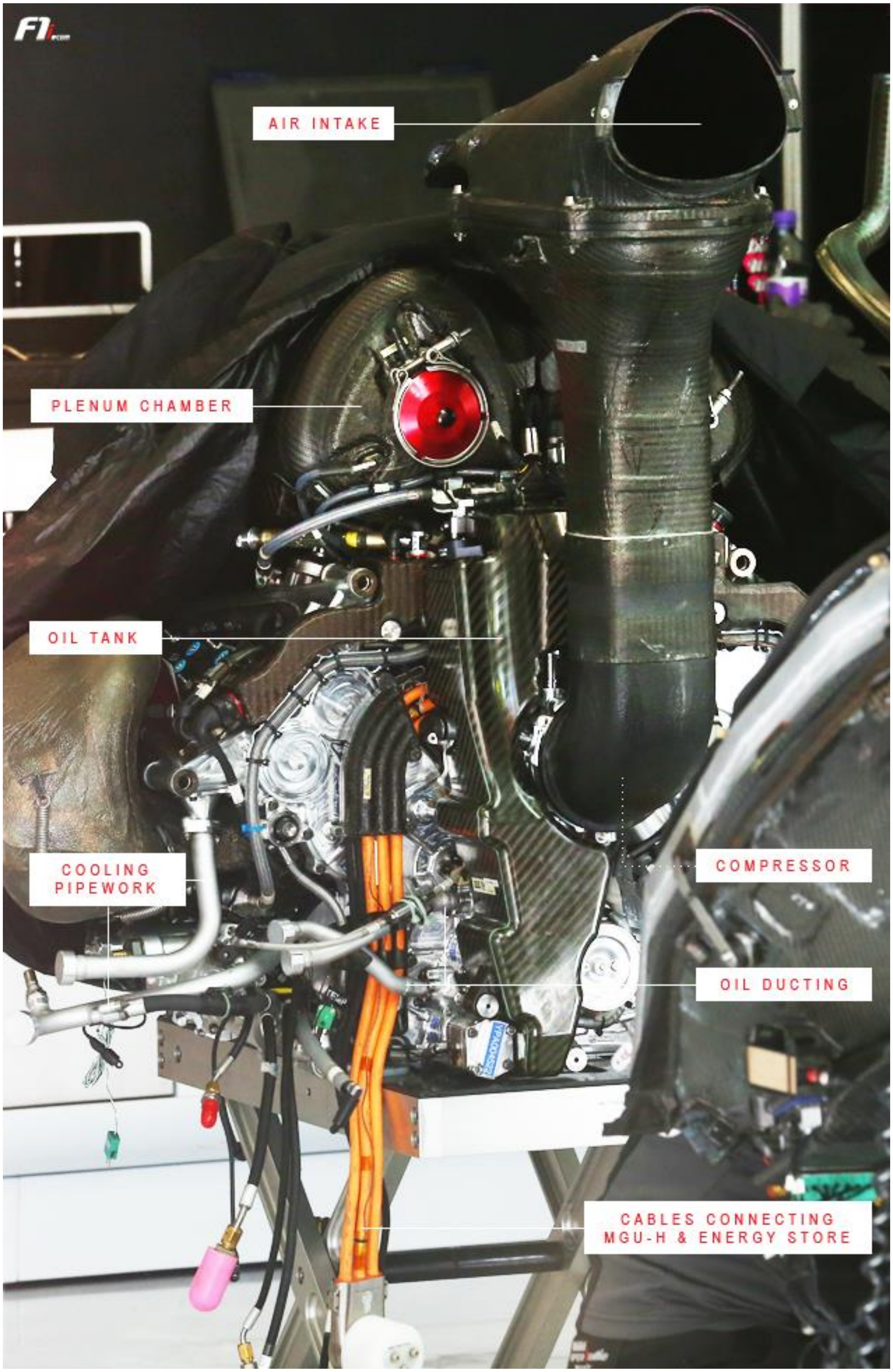


AN INNOVATIVE SETUP

While the compressor and turbine are placed side by side on the Renault and Ferrari power units, Mercedes has kept its original split-turbo setup for the 2015-spec PU106B. The two components are positioned further away from each other than in a more conventional installation. Therefore, the shaft that connects both elements is necessarily much longer, going through the 'Vee' of the engine where, incidentally, the MGU-H sits.
As one can see on the picture above, the compressor is placed at the front of the power unit, while the turbine sits at the back. The periscope-shaped air intake drops forwards to the front of the engine and feeds air to the compressor. This installation has forced Mercedes' engineers to hollow out the oil tank in order to free up some space within the V6. By comparison, Honda, which has also gone for a split-turbo design, has placed the air intake system behind the oil tank.

A THREE-FOLD ADVANTAGE

Mercedes' fairly unconventional architecture offers three advantages. First, it allows better cooling, since the aluminium-made compressor and its associated pipework are mounted at the front of the V6, namely far from the 1000°C released by the red-hot turbine and exhaust. Thus, the compressor can work with a smaller intercooler (the compressed air requires less cooling).
Another advantage comes from the shorter pipework connecting the compressor to the intercooler, which helps reduce the dreaded "turbo lag". Therefore, a lesser portion of the energy recovered by the MGU-H is needed to feed the turbine when the throttle is not engaged. In other words, the Mercedes unit would 'waste' less energy to maintain the optimum rotational speed of the turbine, and have more at its disposal to boost the engine. The PU106B is also able to charge its battery faster. Unlike Honda-powered pilots for instance, Mercedes-engined drivers can deploy the maximum amount of electric energy allowed per lap, using less fuel as a result.


AIR INTAKE
PLENUM CHAMBER
OIL TANK
COOLING PIPEWORK
COMPRESSOR
OIL DUCTING
CABLES CONNECTING MGU-H & ENERGY STORE

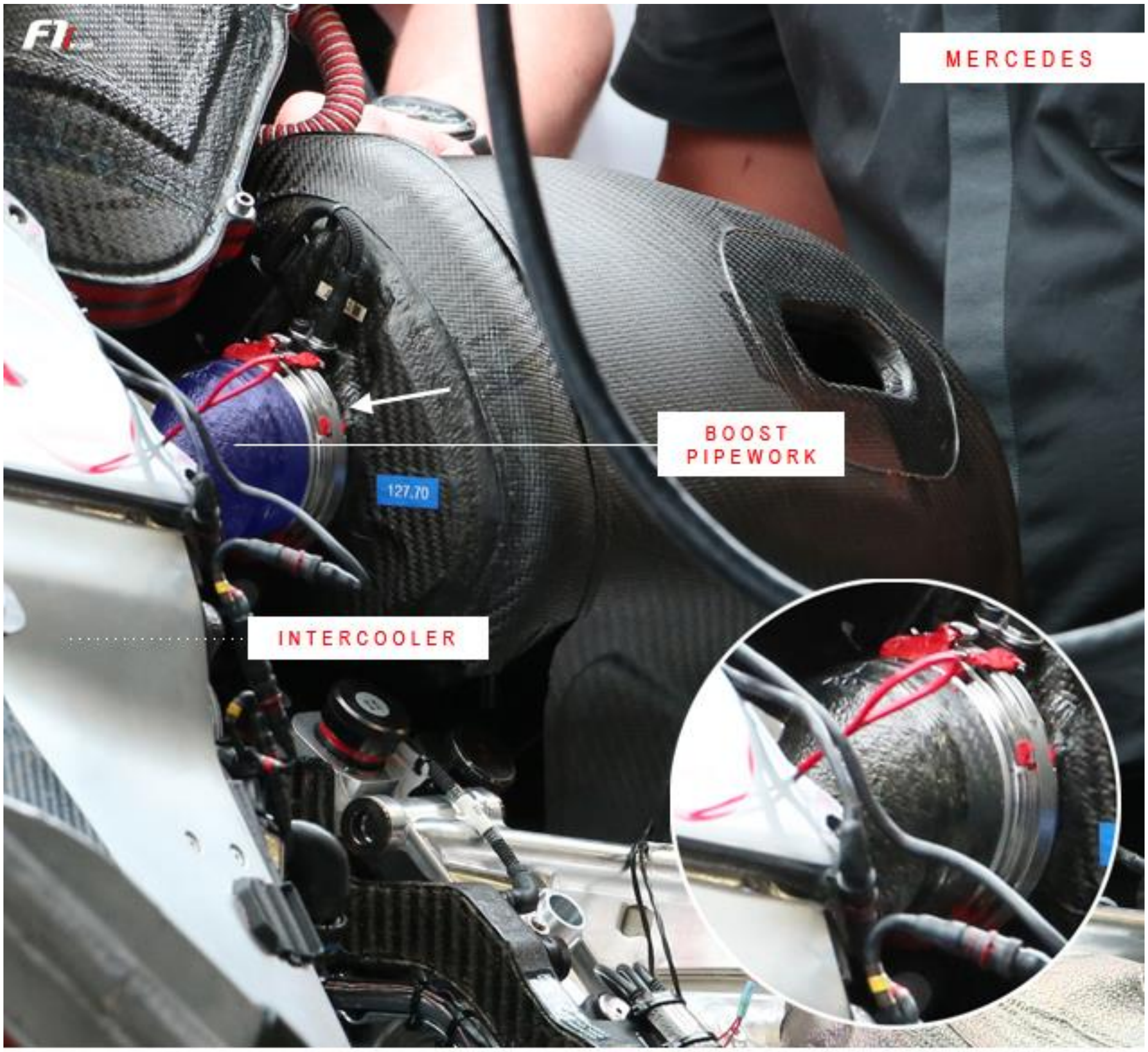
IT'S ALL ABOUT ENGINE INTEGRATION

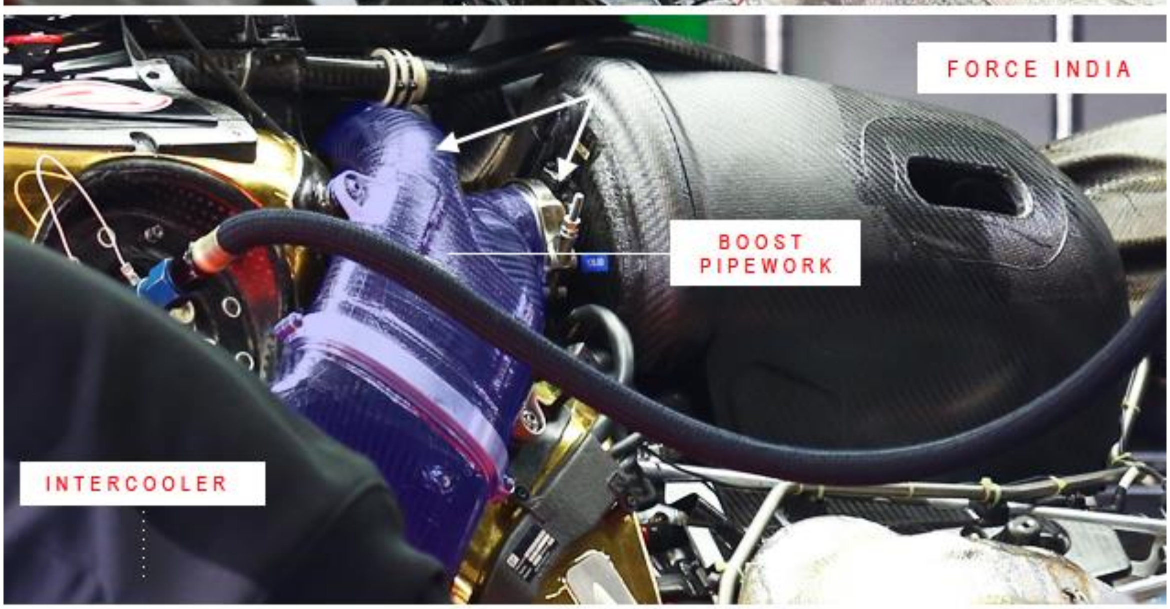
The third asset stemming from Mercedes' power unit architecture is equally major. For starters, one will remember that Red Bull-Renault has a split-intercooler installation – with one element featuring in each sidepod – while Honda has implemented its intercooler within the left sidepod of the McLaren. Meanwhile, Mercedes's chassis engineers from Brackley have worked hand-in-hand with their engine counterparts from Brixworth and come up with a single intercooler design, lodged within the monocoque itself (basically between the driver and the engine). This frees up some valuable space in the sidepods, which in turn limits airflow resistance. By placing its intercooler in the 'Vee' of the engine, Ferrari has followed the same concept of keeping the sidepods clear.

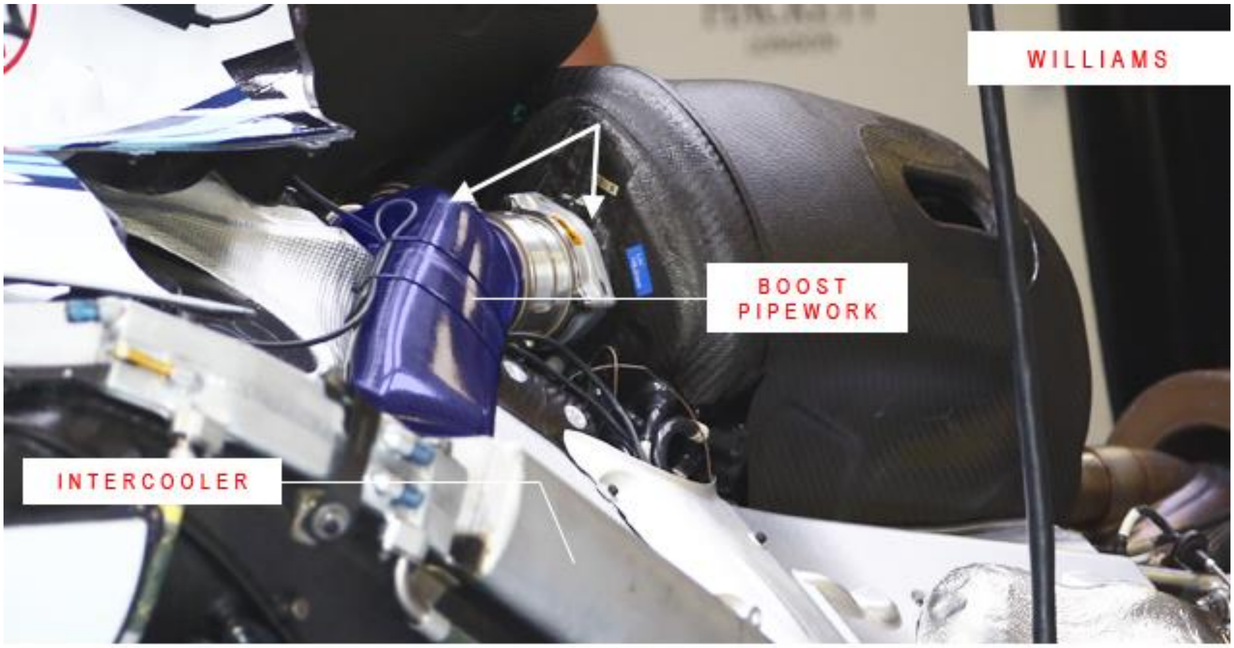
The Mercedes W06 is the only car to have the intercooler (air-to-water) straight within its carbon monocoque, which also allows having shorter boost pipework.
Compared to 2015 customer teams Williams, Force India and Lotus, Mercedes' works outfit enjoys more leeway and time to fully optimise engine integration, thus refining and improving the car's internal aerodynamics. The Silver Arrow is the only machine to have its intercooler (air-to-water) straight within its carbon monocoque, which also allows having shorter boost pipework.

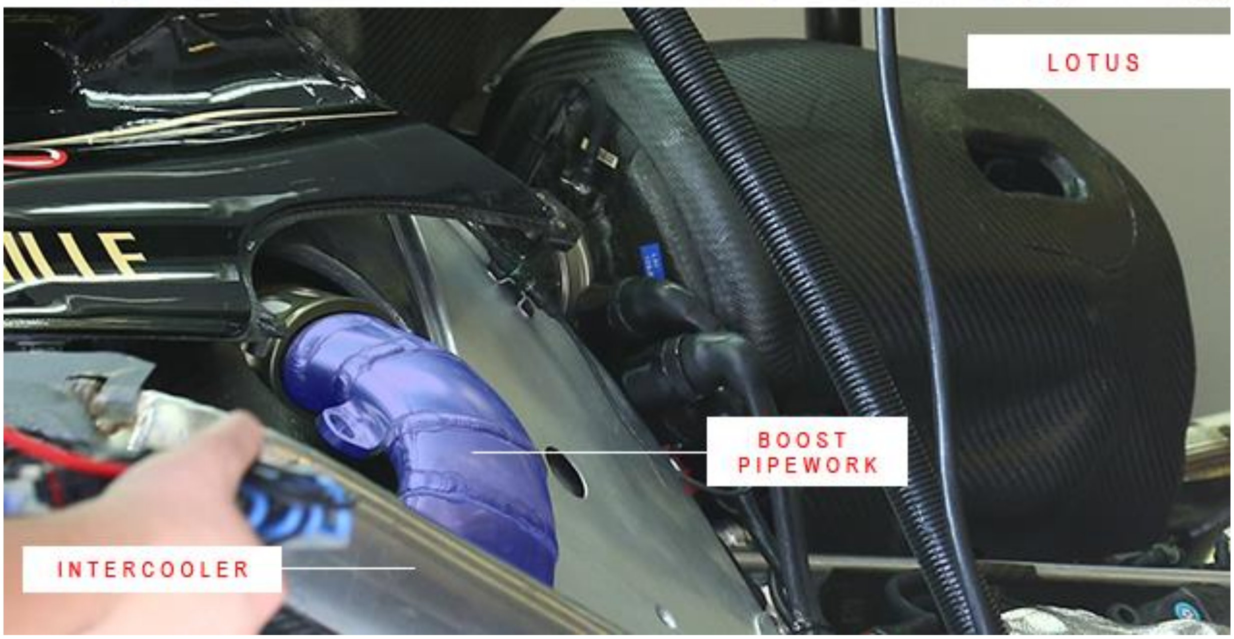
As seen on the picture above, the Williams FW37, Force India VJM08, and Lotus E23 feature an air-to-air intercooler in their left sidepod. On all three cars, the component sits very much at the front of the internal combustion engine (ICE) in order to stay away from the heat released by the ICE and exhaust.

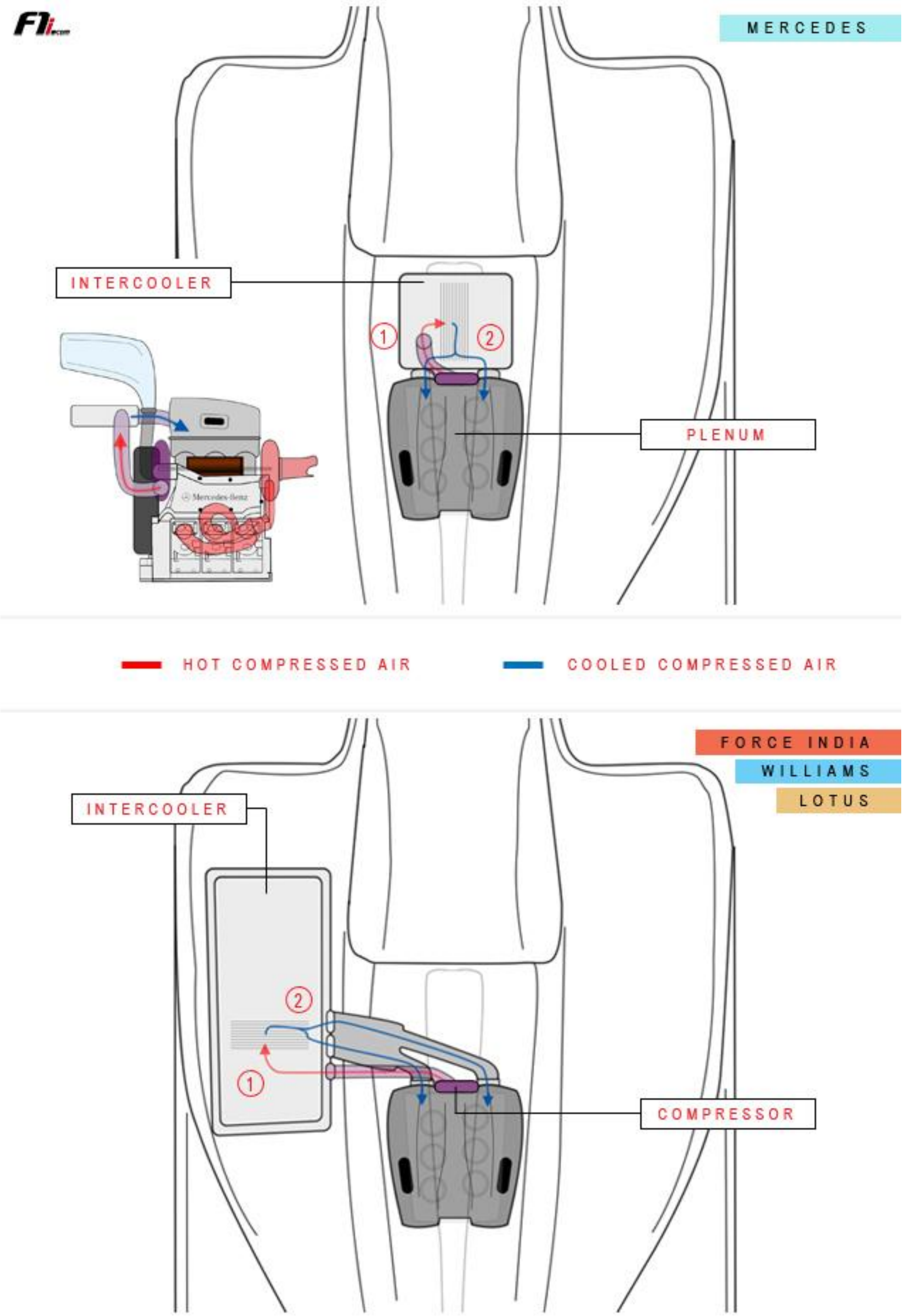
Consequently, the duct that channels compressed air towards the intercooler is definitely longer on these three cars than on the Mercedes. And we mentioned earlier that shorter pipework means more electric energy to boost the engine. Next pages is a diagram that offers a basic comparison between the different Mercedes-powered installations.


MERCEDES
BOOST PIPEWORK
INTERCOOLER


FORCE INDIA
BOOST PIPEWORK
INTERCOOLER


WILLIAMS
BOOST PIPEWORK
INTERCOOLER


LOTUS
BOOST PIPEWORK
INTERCOOLER


MERCEDES
INTERCOOLER
1
2
PLENUM
HOT COMPRESSED AIR
COOLED COMPRESSED AIR
FORCE INDIA
WILLIAMS
LOTUS
INTERCOOLER
2
1
COMPRESSOR

NURTURING IN-HOUSE EXPERTISE

Besides a clever intercooler setup, the ERS (energy recovery system) efficiency of the Mercedes package stems from Brixworth's renowned expertise in that field, more than from the size of the compressor as suggested by some.

When engine manufacturers ran the very first version of the KERS (2009-2013), most of them let their teams develop the system and/or entrusted it to their suppliers (Magneti Marelli for Ferrari and Renault). Mercedes, however, kept fine-tuning the device in house. In 2010, when teams all agreed not to run the KERS, Brackley carried on working on it nonetheless.

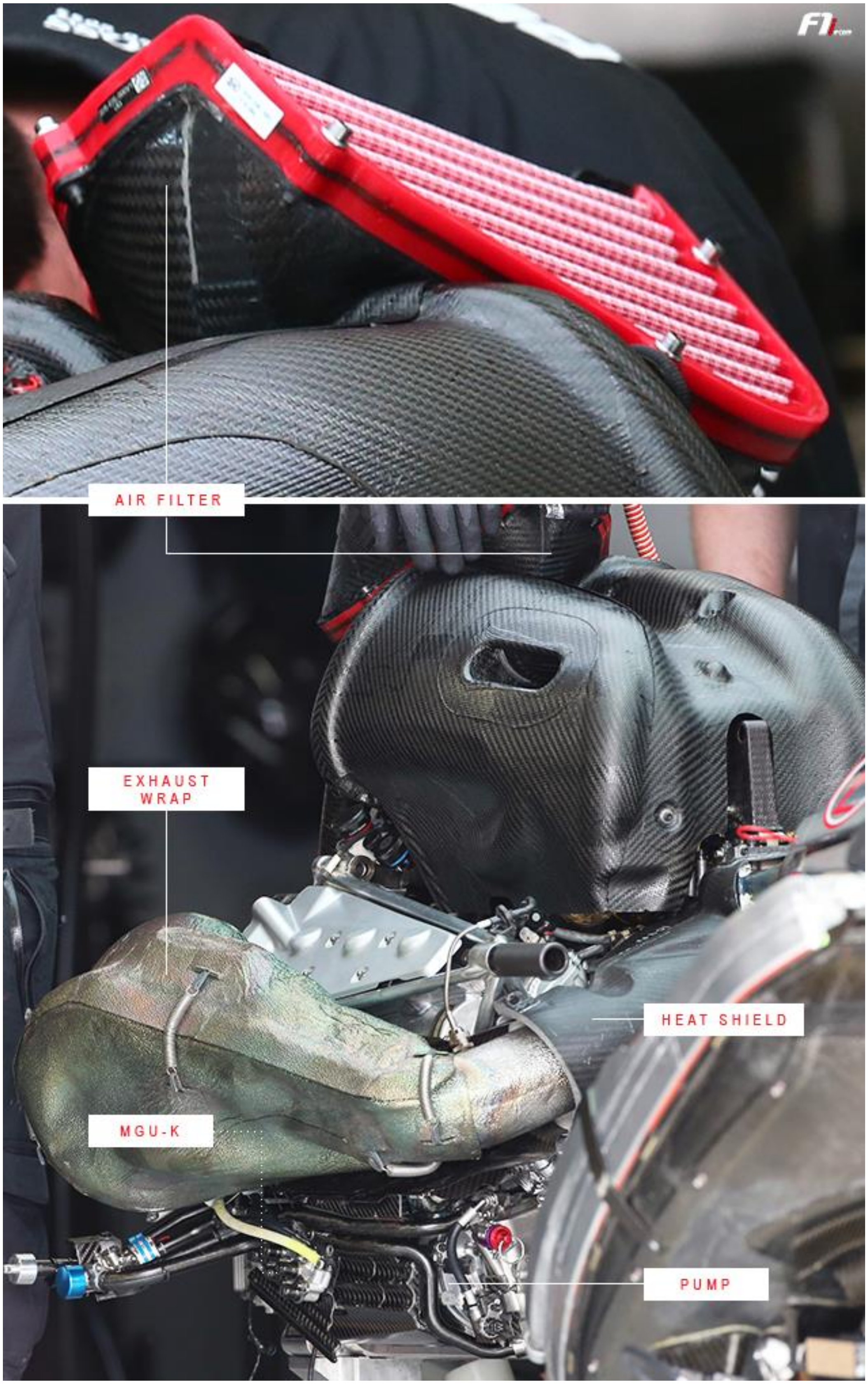
Second-generation KERS were already much more efficient than their 2009-spec predecessors, but restrictions limited the systems to 60kW for 6.7 seconds, somehow masking any major improvements. These systems have now become a major performance factor in the new turbo era.

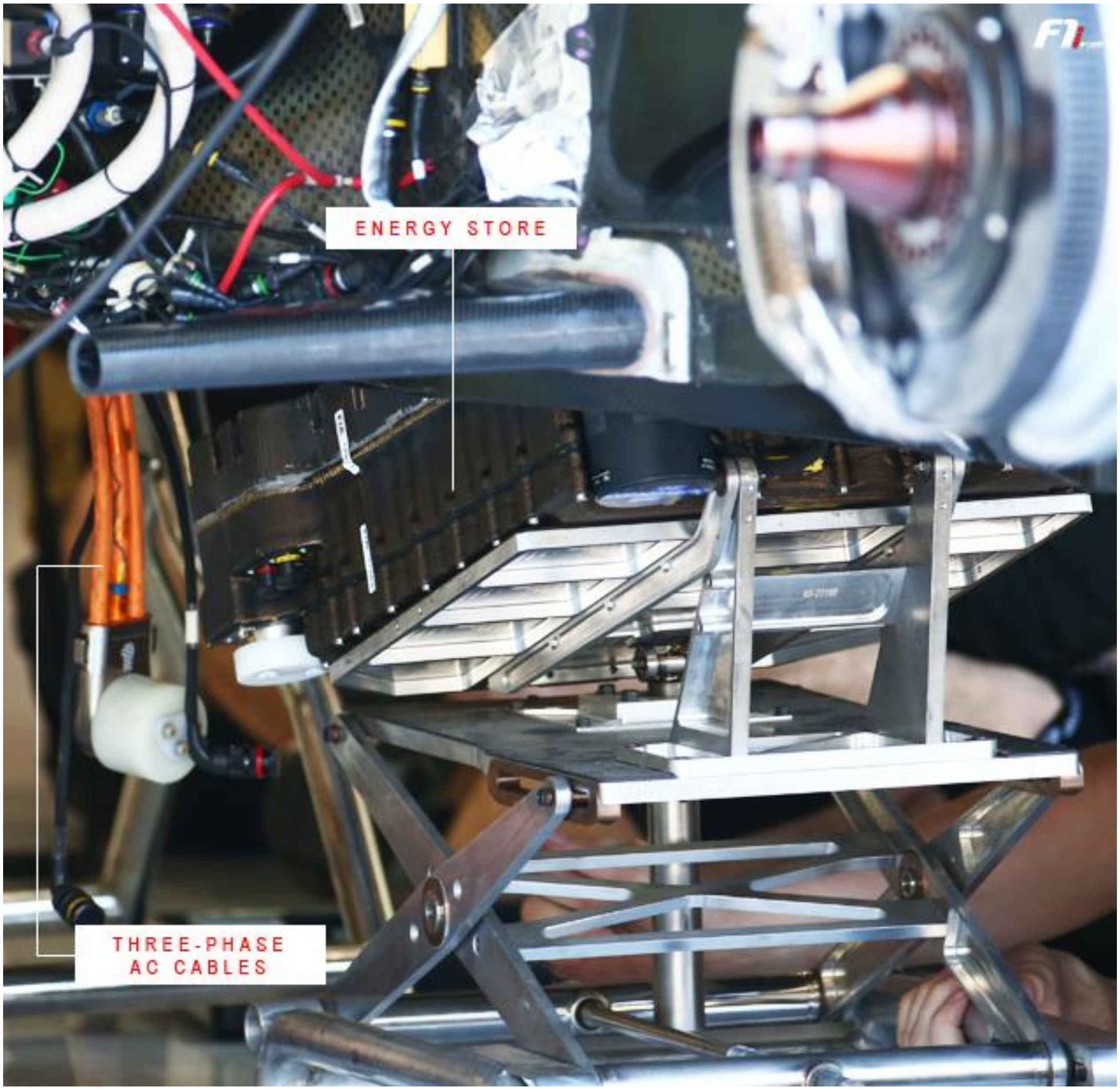
"If [you] just look at the internal combustion engine, then today's V6 1.6-litre turbo-charged engine is approximately the same power as the [2.4-litre normally aspirated] V8 engine was," Cowell says.

"Both of those ran a hybrid system and if you add the KERS system onto the V8 and the ERS system onto the V6, and look at their maximum power values, then today's V6 with ERS is 10 per cent more powerful than we had with the V8 and the KERS system.

"The ERS system is available for the majority of the lap; the KERS system was only available for 6.7 seconds of the lap, so in terms of laptime impact of the V6 and ERS, it is significantly greater than we had with the V8 and KERS system."

On the picture above, one can notice that Mercedes has ditched its trademark log manifold – one the most distinctive feature on last year's PU106A – and replaced it with a more conventional multi-tube exhaust design.


AIR FILTER
EXHAUST WRAP
HEAT SHIELD
MGU-K
PUMP


ENERGY STORE
THREE-PHASE AC CABLES

ALWAYS STRIVING TO STAY ONE STEP AHEAD

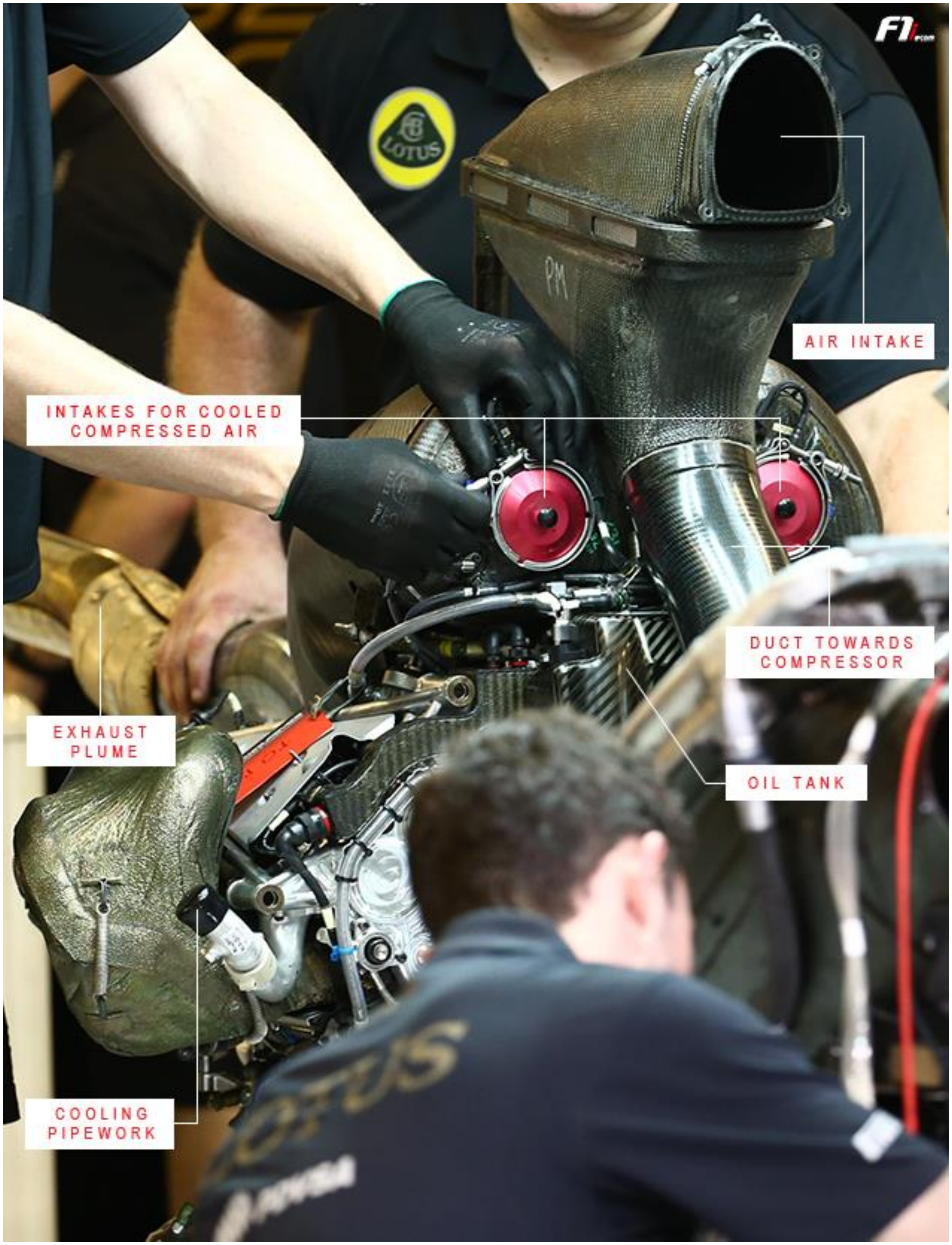
The Italian Grand Prix saw Mercedes introduce a major upgrade of its PU106B, with a view towards developing its future 2016-spec power unit. The world champions spent their entire seven-token allocation on the new specification, with three tokens devoted to an ICE overhaul, most specifically to the "combustion aspect". Meanwhile, fuel partner Petronas provided Mercedes with a new product in an effort to unlock the full potential of the new package. The upgrade was run across eight grands prix, a valuable sample size for engineers to analyse and assess their technical choices in real conditions and see what can be further improved ahead of next year.

"It's a good point to introduce and do that development work and then build [the 2016 engine] on that through the winter," Cowell commented.

"The fuel enabling us to make changes around the internal combustion engine is where the majority [of the upgrade] is.

"The combustion aspect linked with the fuel is the key, but there are some other enablers [where the other four tokens were spent] close to that to pull the whole package together."

However, Mercedes and its rivals will have to rely solely on the dyno to test the new exhaust tailpipes, which have been devised in the new-for-2016 technical regulations to make next year's power units louder. Instead of one single tailpipe for both the turbine and wastegate(s), the new layout will feature one tailpipe for the former and one or two smaller ones for the latter.


AIR INTAKE
INTAKES FOR COOLED COMPRESSED AIR
DUCT TOWARDS COMPRESSOR
EXHAUST PLUME
OIL TANK
COOLING PIPEWORK

A WINNING COMBINATION

If we were to summarise Mercedes' advantages, one could say that the PU106B combines the benefits of the Renault setup – a compact V6 – with those of the Ferrari installation – no intercooler in the sidepod. We recently showed Renault Sport F1 director of operations Remi Taffin a diagram of the Mercedes power unit; here are his thoughts:

"We could say that they have gathered the best of both worlds, since the MGU-H sits within the 'Vee' and the intercooler lodged somewhere in the chassis, which frees up space in the sidepods.

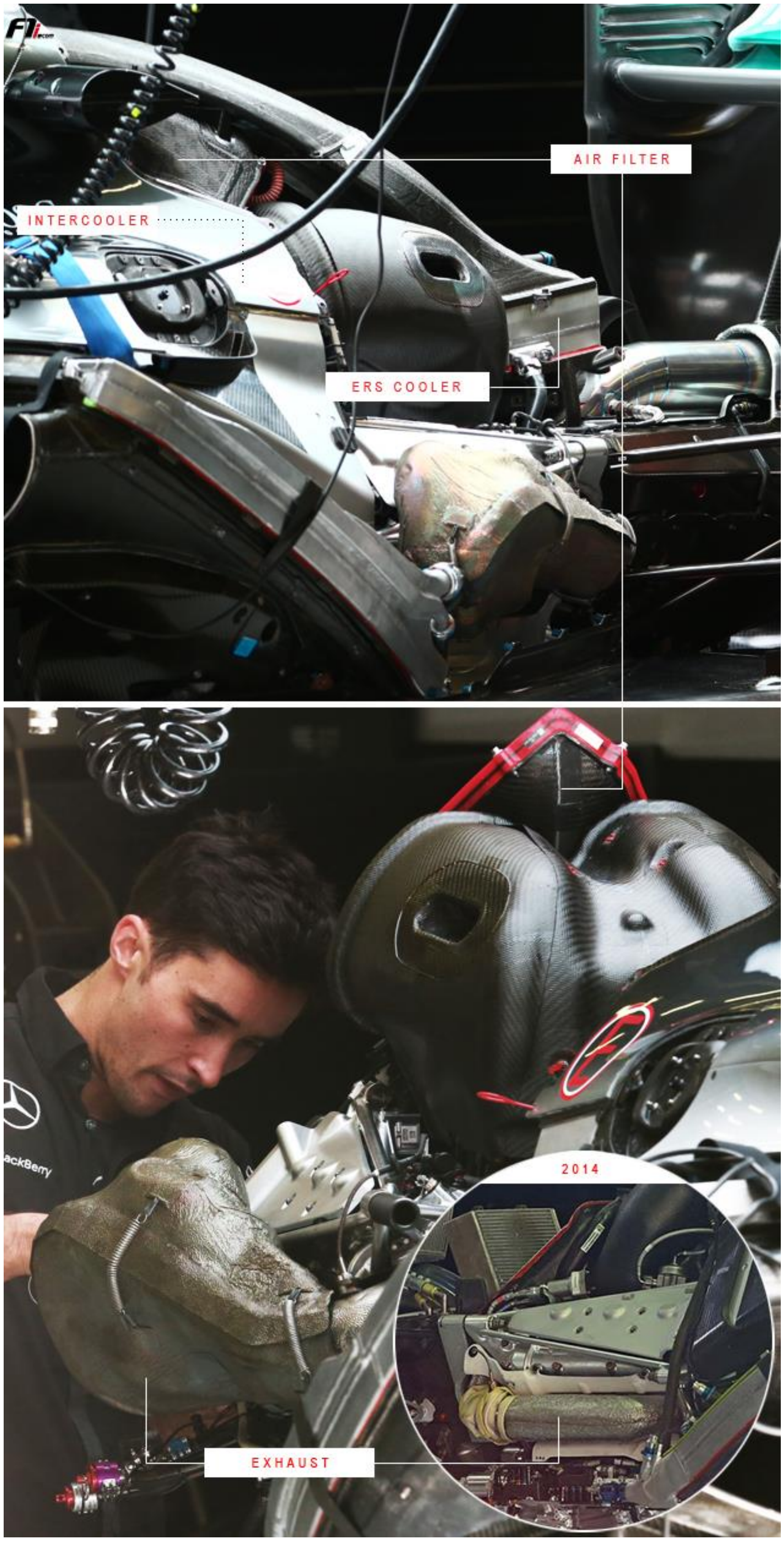
"However, this architecture features other constraints. When the compressor is split from the turbine, the shaft [that connects both elements] is very long, which cause some problems, most notably in terms of dynamics.

"That said, the topic of transient phases needs to be addressed. These are turbocharged engines, so there is a response time. The pipework here [on the Renault power unit] are longer than there [on its Mercedes counterpart]."

Theoretically, Mercedes' main structural flaw should come from the unusual length of the turbine shaft. This makes it more vulnerable, especially when rotational speeds reach 125,000rpm (not to be confused with engine rpm). As a result, the shaft needs to be extremely stiff, but Mercedes's PU106B does meet this requirement.

Its seamless integration within the W06 chassis is the main reason why the Toto Wolff and Paddy Lowe-led team has been so dominant over the past two years. Mercedes took up the challenge presented by the new power units and succeeded better than its rivals thanks to the very early and close-knit collaboration between its factories at Brackley and Brixworth, separated by only 27 miles.

In order to shake up the established order, Honda and Renault – which has confirmed its return as a works outfit – will need to really speed up their recovery, while Ferrari must not drop the ball after making noticeable inroads in 2015.


AIR FILTER
INTERCOOLER
ERS COOLER
2014
EXHAUST

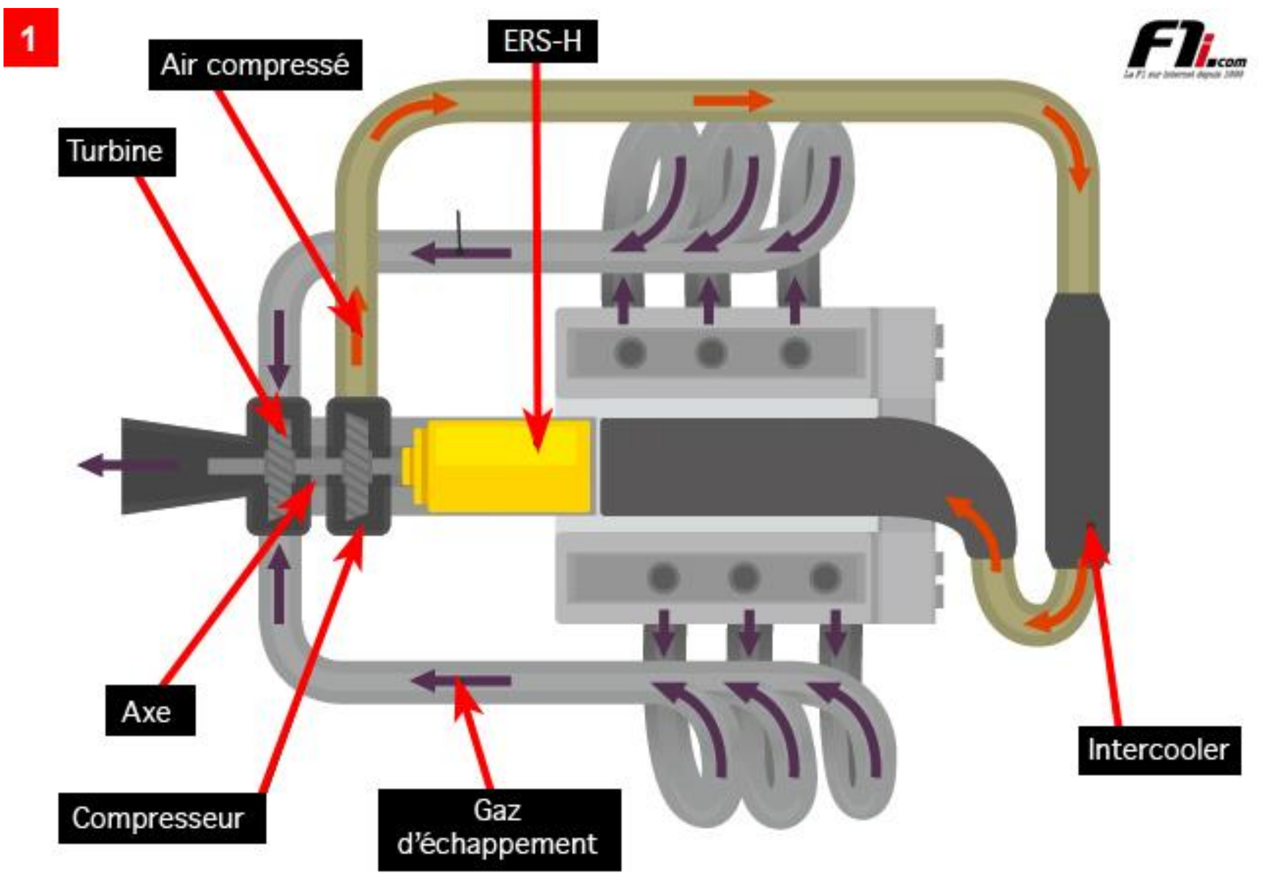
7.3.2 Tips of the Mercedes Power Unit

Associated with two energy recovery systems, the thermal V6 engines used this season are based on the technology of overeating, introduced by Renault in 1977. The turbo principle is to supercharge the engine with air to increase the pressure of the intake air, thereby improving the filling of the mixing cylinders air/fuel, thereby increasing the power for the same displacement.

Typical Installation

Simplifying very much, a turbo consists of three parts: a turbine, a compressor and an axis, which connects them. The turbine positioned in the flow of exhaust gas exiting the engine is driven at high speed. It is connected by a shaft to a compressor disposed in the engine intake conduit. This compressor sucks and compresses ambient air before sending it into the cylinders through an air/air heat exchanger to cool (or, more rarely, by an air/water, as do Ferrari and Mercedes).

In general, the turbo is a compact unit placed at the rear of the engine, as shown below. Such is the classical architecture chosen by Renault for its V6. The axis connecting the compressor to the turbine is very short. And the ERS-H, which recovers the energy expended by the rotation of the shaft, is placed inside the "V" formed by the two rows of cylinders.



Mercedes has chosen a more original implementation, breaking, somehow, the turbo. Contrary to the official broadcast images showed during the presentation, the turbine is separated from the compressor on the German V6.

In other words, the turbine is always mounted at the rear of the block, while the compressor is placed in front. The two elements away from each other more than in a conventional architecture, are connected by a much longer axis, which passes inside the "V", as shown below (the tube of admission and air box have been drawn dotted here to make visible the architecture and the length of the axis). "On production cars, underlines our technical consultant Jacky Eeckelaert, the shaft is as short as possible, for reliability issues. But with such a provision, it could be quite accommodate the ERS-H generator between the turbine and the compressor".

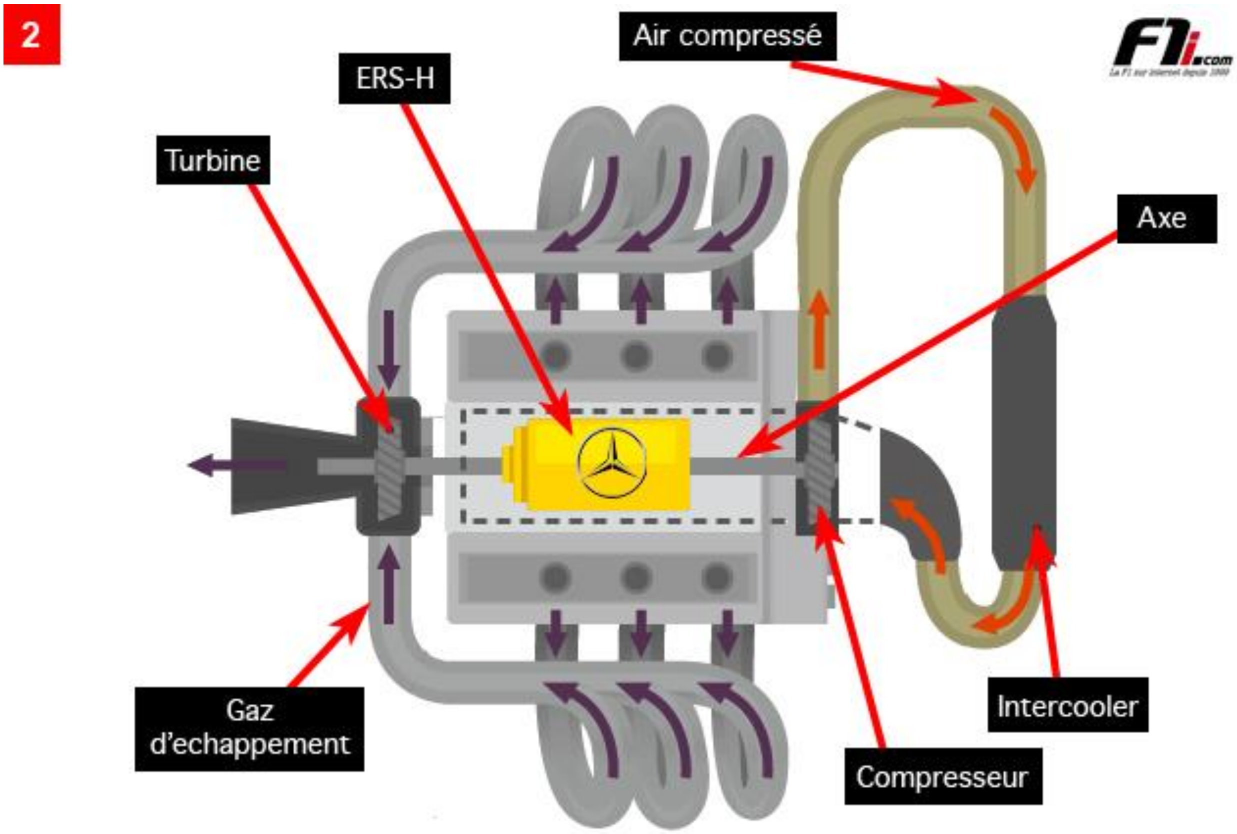
Mercedes Innovation

This architecture, unusual, has two advantages. The first is a better management of cooling, since the aluminum compressor and conduits are mounted on the front of V6, far from the 900°C of the turbine and of hot exhausts. The exchanger can therefore be smaller (because compressed air has less need to be cooled), which allowed the aerodynamicists to draw closer side pods.

Secondly, the pipes connecting the compressor to the heat exchanger are shorter, which reduces the famous "answer period" of the turbo. However, lower the response time reduces the amount of energy to be stored by the ERS to continue to rotate the turbine when the accelerator pedal is not pressed. So the battery discharges less rapidly, which is a significant gain when we remember that the law authorizes spending 4 MJ per lap but to recover only 2 MJ per lap.

Thirdly, placing the compressor in front of the block, Mercedes cleared space at the rear, which has the advantage of advance a little gearbox, hence a better center of gravity.

The possible failure of this implementation is the unusual length of the shaft, making the most vulnerable part: led to 125,000 revolutions / minute (rotation speed of the turbine, not to be confused with the engine speed), the shaft must have an exemplary reliability, which seems to be the case at Mercedes (the failure of Hamilton Australia is due to a hole in the rubber seal that protects the spark plugs; this cavity prevented a candle to fire and, therefore, a cylinder failed).



Bien entendu, cette particularité du bloc PU106A n'explique pas à elle seule la compétitivité des monoplaces propulsées par Mercedes (Force India, Williams, McLaren) ni la suprématie des Flèches d'argent. Pas plus que son refroidissement par un échangeur air/eau, qu'il partage avec le V6 Ferrari (expliqué ici). Plus globalement, c'est la capacité des motoristes de Brixworth à faire fonctionner le bloc thermique en harmonie avec les deux systèmes de récupération de l'énergie qui explique l'excellence du propulseur étoilé.

Intégration en amont

Quant aux performances exceptionnelles de la W05, elles reposent sur l'alliance d'un bon moteur et d'un châssis efficace, et sans doute aussi sur le fait que les écuries clientes ont reçu plus tard leur propulseur et ont donc eu moins de temps pour étudier les détails de son intégration dans le châssis… Les ingénieurs de Brackley ont travaillé main dans la main, et très en amont, avec leurs collègues motoristes de Brixworth, installés à une quarantaine de kilomètres de l'usine.

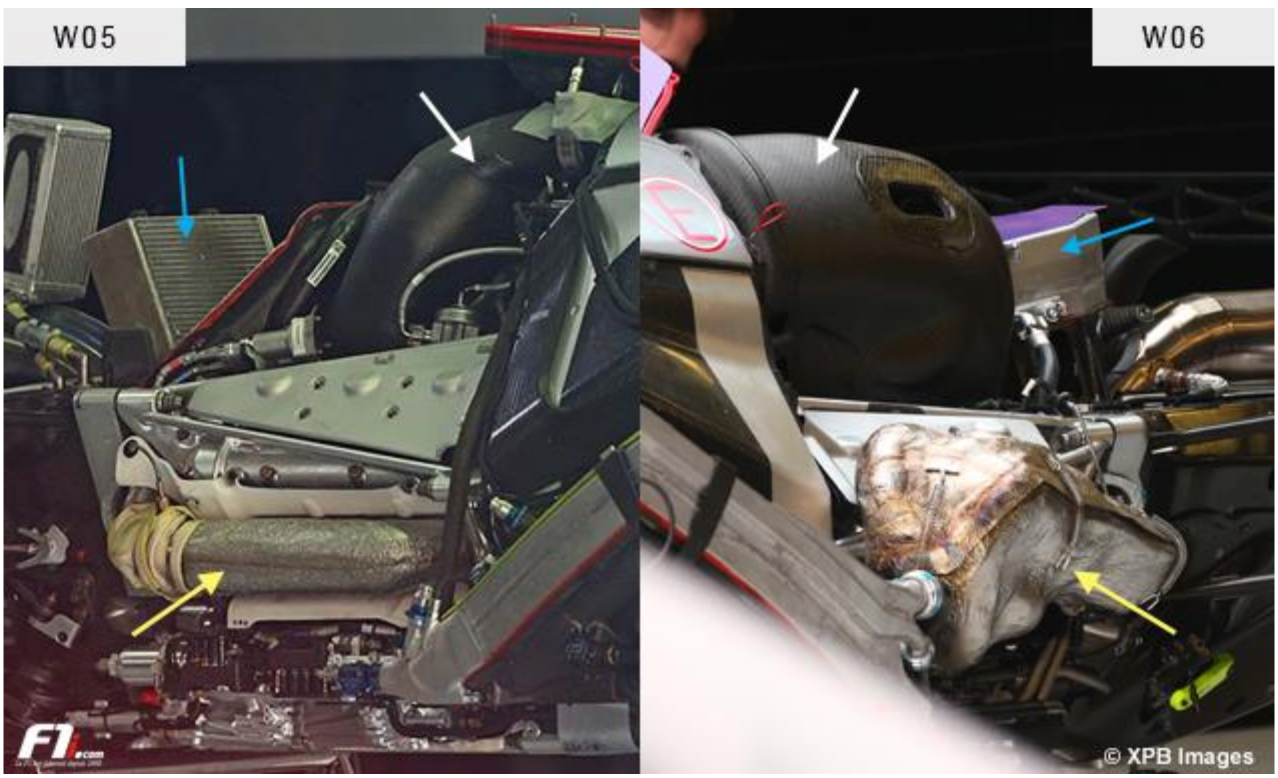
7.3.3 Mercedes far from being exhausted

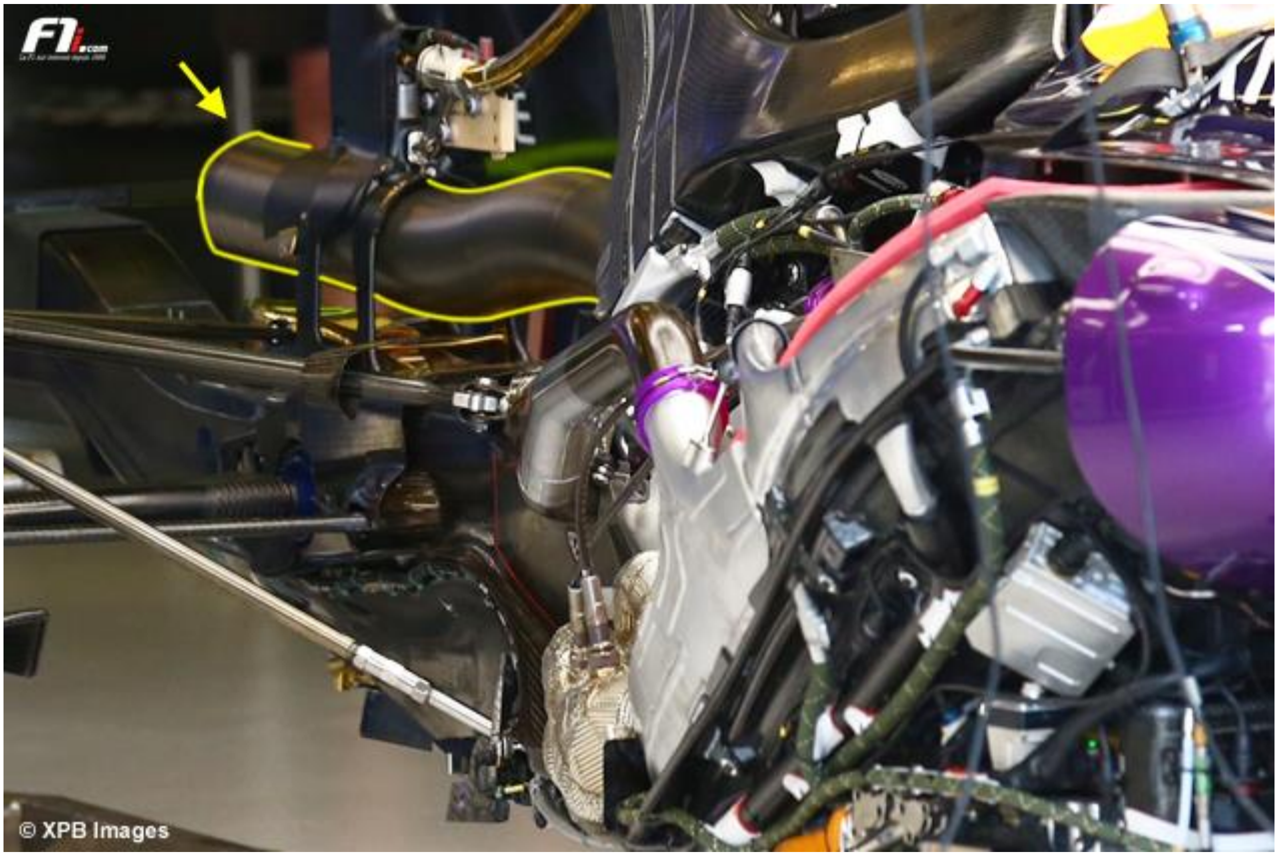
Both Silver Arrows flew by like shooting stars in Melbourne, with the first non-Mercedes car of Sebastian Vettel finishing 34.523s adrift of race winner Lewis Hamilton in his W06 Hybrid. This means an extra ten seconds compared to last year's gap of 24.525s between Australian Grand Prix victor Nico Rosberg and second-placed Daniel Ricciardo (although the Aussie would eventually be disqualified).

Mercedes' 2015 challenger is very good aerodynamically through fast corners – even though this comes at the expense of the car's top-end speed – but the W06 also benefits from an upgraded PU106A power unit. Indeed, the engine technicians at Brixworth have used up more development tokens (25) than their counterparts at Ferrari (22) and Renault (20).
One change is particularly noticeable on the German behemoth's 2015-spec power unit. It no longer features its distinctive log manifold, which used to be one the most distinguishing element on last year's package. On each side of the V6, a single open pipe placed very close to the engine would collect the gases that were burnt in the three cylinders before feeding them towards the turbine via exhausts ducts. This year, Mercedes engine boss Andy Cowell and his team at High Performance Powertrains have gone for a more conventional manifold design: each cylinder has its own exhaust, with the three pipes then merging into the collector.

BENEFITS AND LIMITATIONS

Each solution has its own advantages. The log-style exhaust is quite short, which helps prevent exhaust gases from losing too much pressure on exit. This also means that more energy is consequently fed towards the turbine, and then harvested by the MGU-H. However, engineers have to keep an eye for any potential collisions between the different gas molecules, which in turn might create turbulences. Last but not least, the compactness of the log manifold package offers great reliability while also giving more freedom to aerodynamicists.
On the other hand, the more conventional tubular exhaust systems have a longer size and thus lose some pressure at the turbo, but this design offers more leeway to regulate exhaust gases across all RPMs. By switching to a more traditional manifold, which seems to be implemented directly onto the engine, Mercedes somehow indicates that they have been able to find a way to maintain high pressure at the turbine. Would it be another masterstroke from Cowell and his team?





The length and diameter of the pipes, the collector angle, etc. all these elements have a critical impact on how well an engine can 'breathe'. The very same pipe can have several different diameters in order to create shock waves that resound back and help improve charging. Taking into account fluid dynamics and vibrations in the exhaust gas column, engineers eventually come up with complex, tangled and twisted pipe designs, which are optimised to reach better turbocharger efficiency.

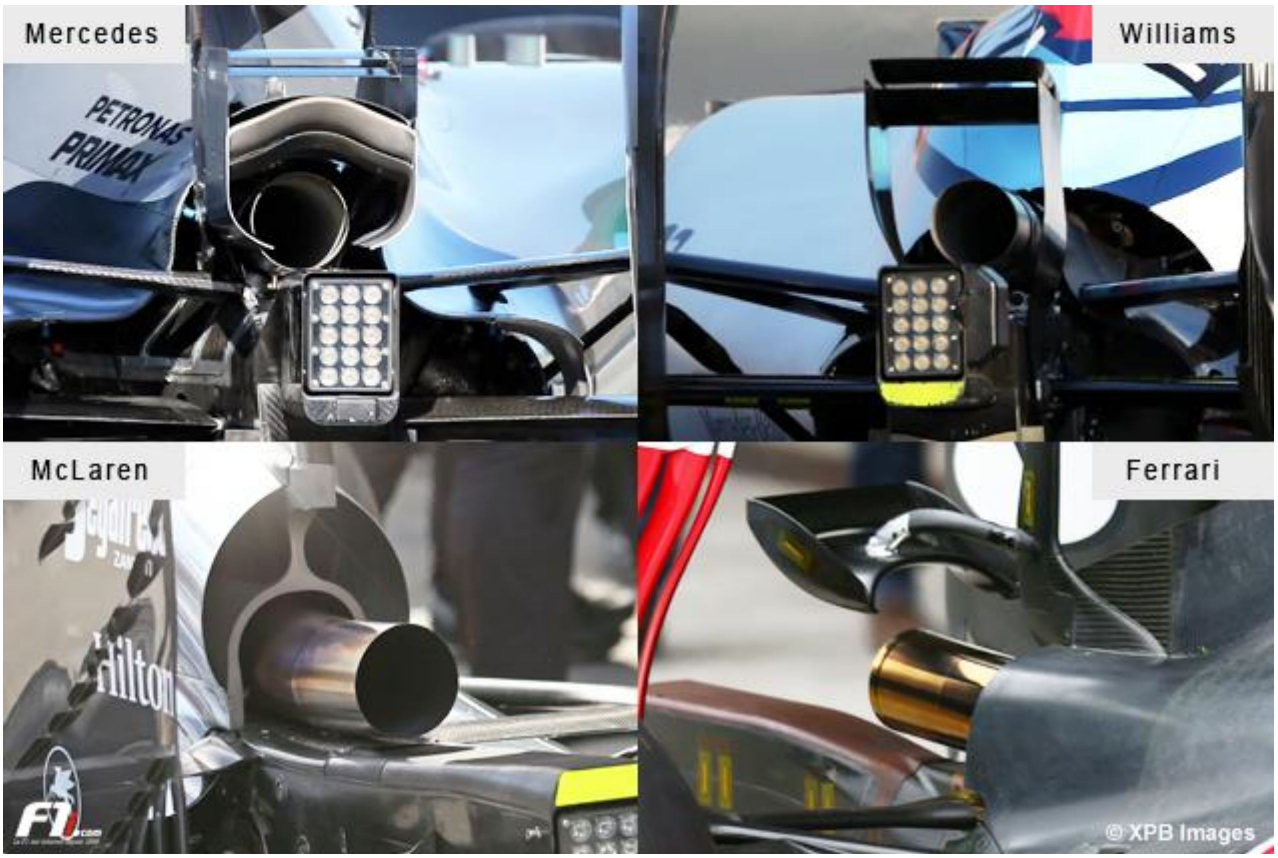
EXHAUSTING ALL THE TECHNICAL OPTIONS

Once the turbine has recovered energy from the exhaust gases, these are vented through a single exhaust that has been clearly defined by the FIA technical regulations. Article 5.8.2 reads that "engine exhaust systems must have only a single tailpipe exit" (instead of two prior to the season 2014), with the pipe's diameter also being regulated.

The circular end of the tailpipe must lie "between 170mm and 185mm rearward of the rear wheel centre line" while also being located "between 350mm and 550mm above the reference plane". What's more, the last 150mm of any tailpipe must point upwards at a maximum angle of five degrees, with no deflector or vane allowed behind the pipe's axis save for the 'monkey seat' winglet.

Only a single tailpipe exit is allowed

The idea is to prevent F1 teams from using exhaust gases for aerodynamic gains, as they used to do with their 'Coanda' systems before 2014. While there remains little energy on exit to be used aerodynamically, most of the squads blow gases below the 'monkey seat' winglet in order to generate more downforce. The governing body's technical regulations also specify that all exhaust gases must pass thought the single tailpipe, with the wastegate diverting part of it in order to relieve the turbine wheel.

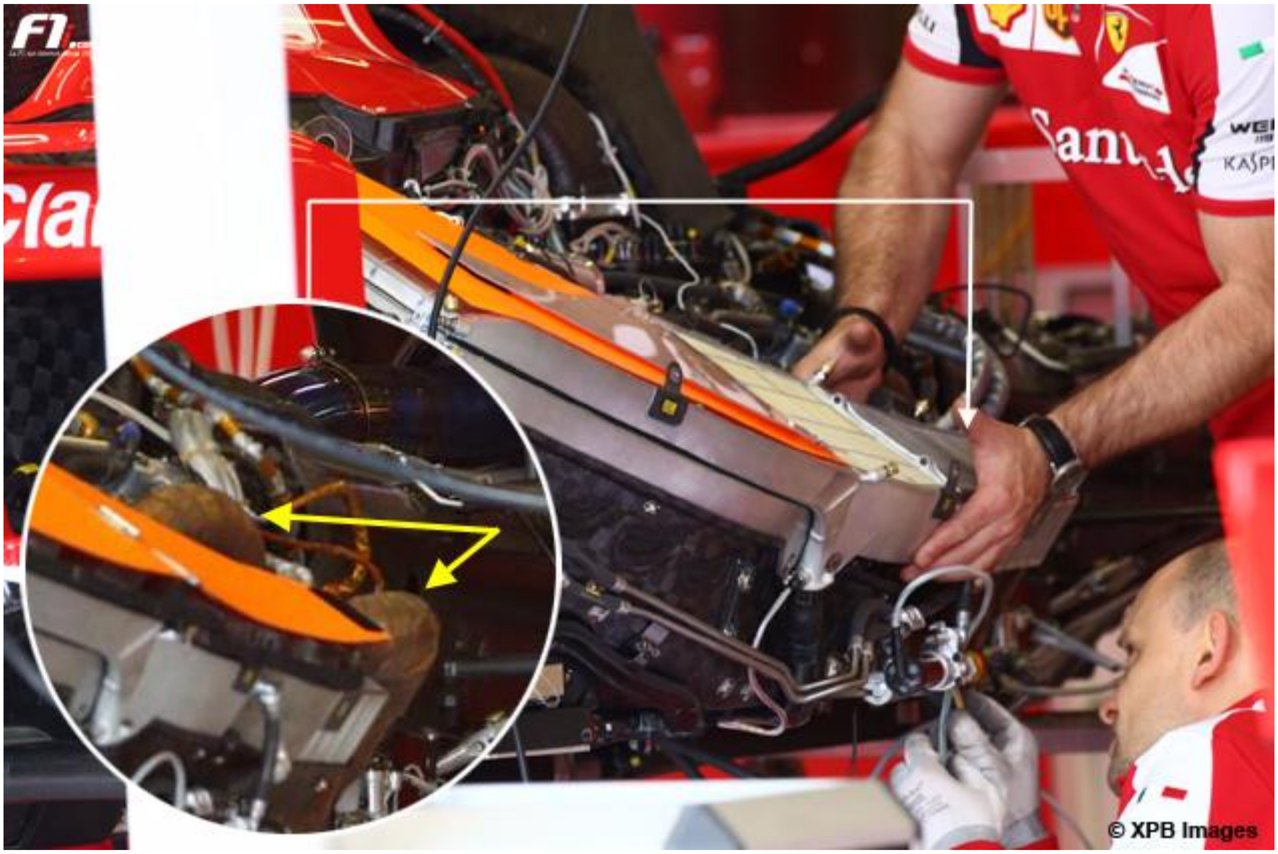


With F1 engineers always looking to save some weight on the cars, pipes are thus made of thin metal sheets. However, this solution increases heat loss, which in turn hinders the functioning of any turbocharged engine. Indeed gases contract upon cooling down, pressure then drops, and so does the turbine rotational speed eventually. This is why teams wrap up the exhaust pipes in a kind of insulating blanket (see picture) in order to maintain heat in the manifold and foster the expansion of gases.

Having to endure temperatures of nearly 1,000 degrees and cope with extreme forces, exhaust pipes are built with a specific metal alloy called Inconel, which comprises of approximately 60% Nickel and 22% Chromium, along with some Molybdenum and Niobium. Inconel is not an easy material to fine-tune though, hence the pipes being made of many small parts and the need for genuine experts to look after the whole assembling process.

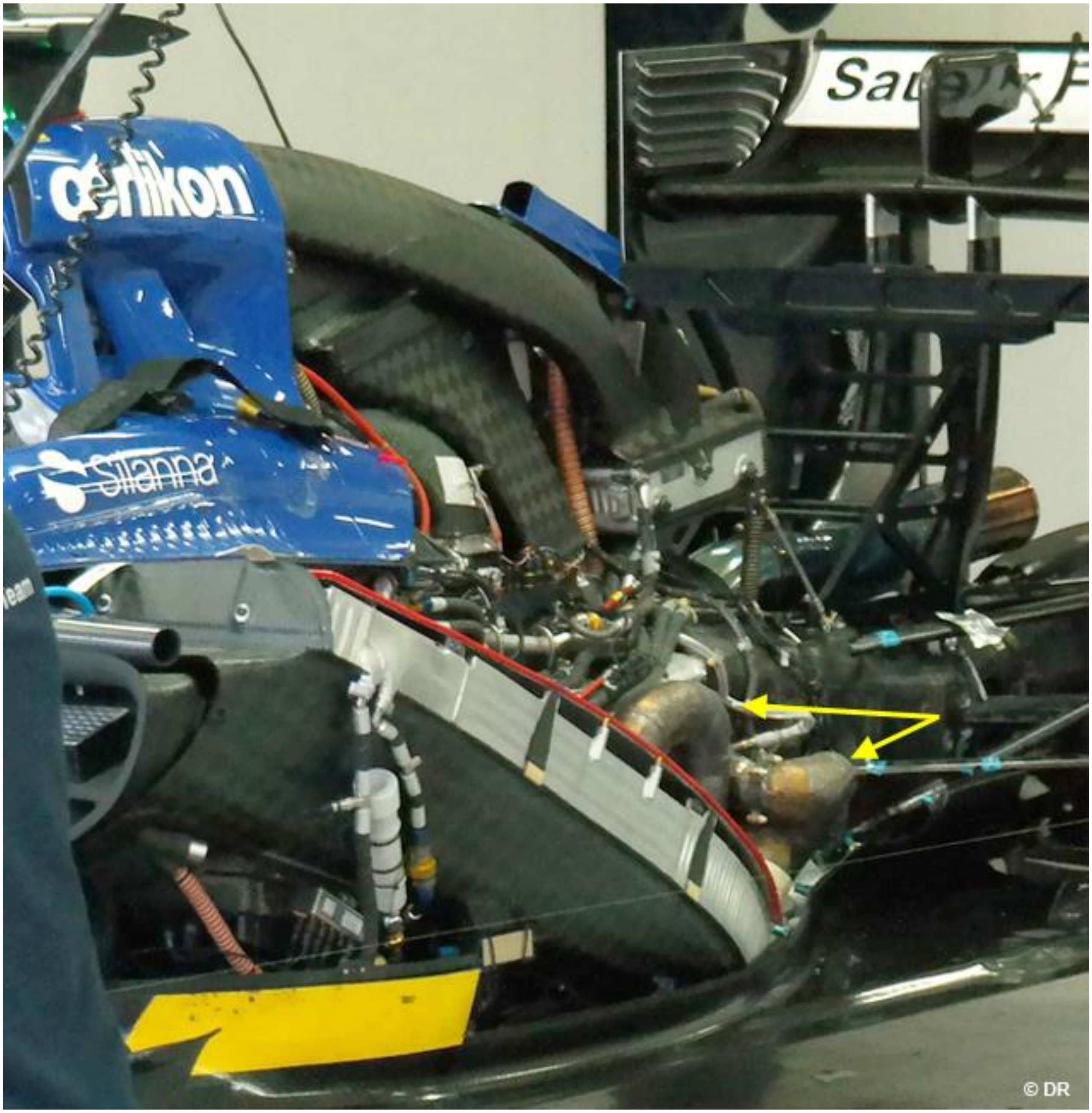
Mercedes has thus followed the same design philosophy as Renault and Ferrari in terms of using a more conventional manifold, as you will see over the next pages.

Red Bull-Renault
The RB11's exhaust pipes are located at a much lower level than on the W06 Hybrid and do not seem to sit as close to the engine as on the Mercedes unit.



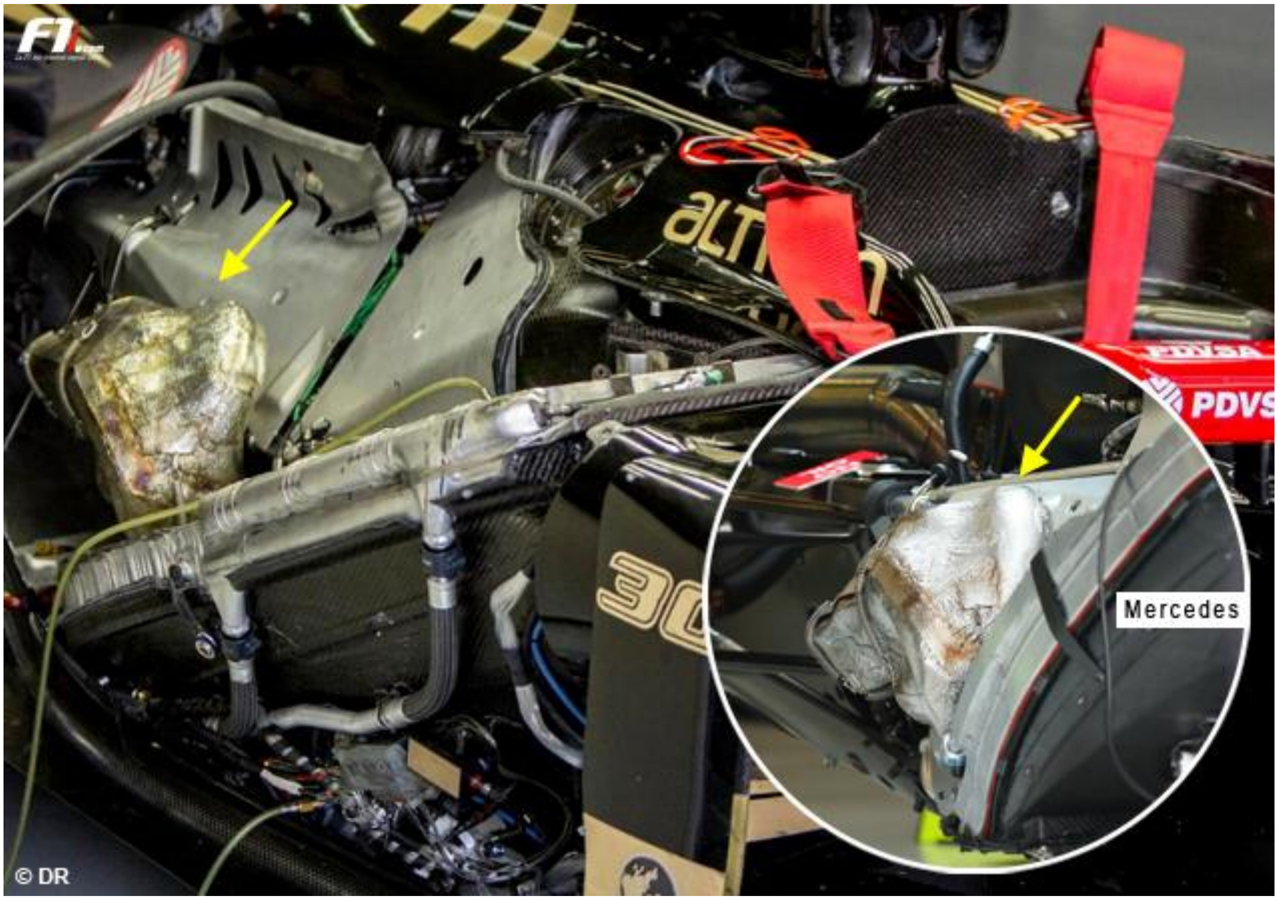
Ferrari

When it comes to the installation of the exhaust systems on its SF15-T, Ferrari's concept leans more towards a Red Bull philosophy than towards a Mercedes design. What's more, the Italian engineers have decided to cover each pipe with an insulating bandage instead of wrapping up the whole manifold in a heat-keeping blanket.



Sauber-Ferrari

The design of the exhaust pipes is pretty identical on the Ferrari and Sauber, with both teams using the same 059/3 engine. Labyrinthine systems indeed!



Lotus-Mercedes
On the Mercedes-powered E23, the exhaust systems are similar to their W06 counterparts, albeit separated from the engine by an insulating wall.

7.4 THE RENAULT POWER UNIT 2015

7.4.1 The RS15

A FAIRLY CONVENTIONAL INSTALLATION

Renault has kept its fairly conventional power unit design on its Energy F1-2015, i.e the compressor is placed side by side with the turbine. Basically, a turbocharger comprises of three main elements: the turbine, the compressor, and a shaft to link them both. The turbine is positioned in the exhaust gas stream, which makes it spin at high-speed. The device is also connected to a compressor that sits below the engine intake. The said compressor sucks up and compresses ambient air, which still needs to be cooled down before being channelled towards the cylinders.

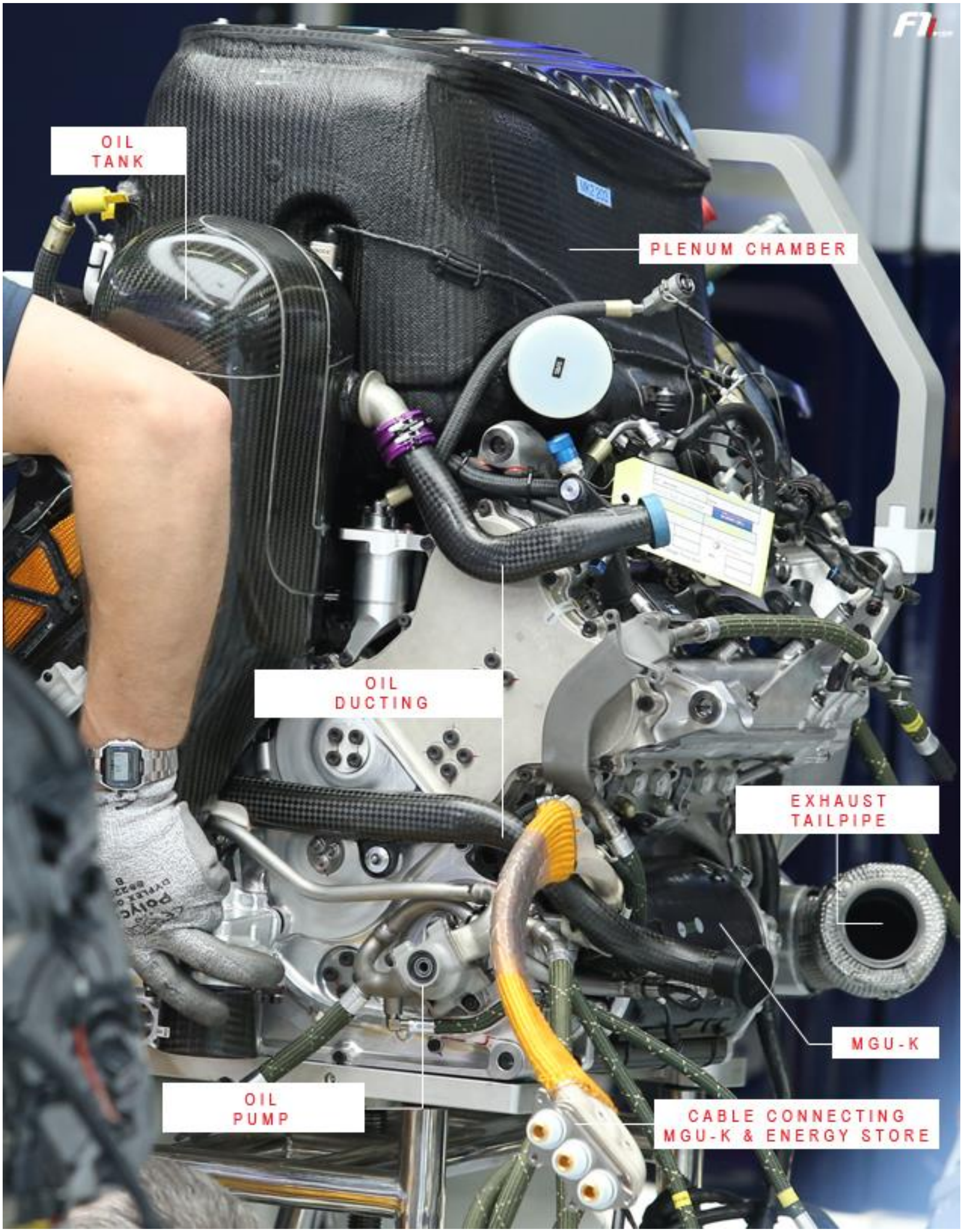
The turbocharger forms a compact assembly at the back of the French power unit. As shown on the picture above, the front of the engine is devoid of any component involved in the charging process. This is a stark contrast to Mercedes' split-turbo installation that has the compressor placed at the front, while the turbine is positioned at the rear (see comparison below).

Only the oil tank is attached to the front of the French hybrid power unit, with oil being extracted from the lower tube.

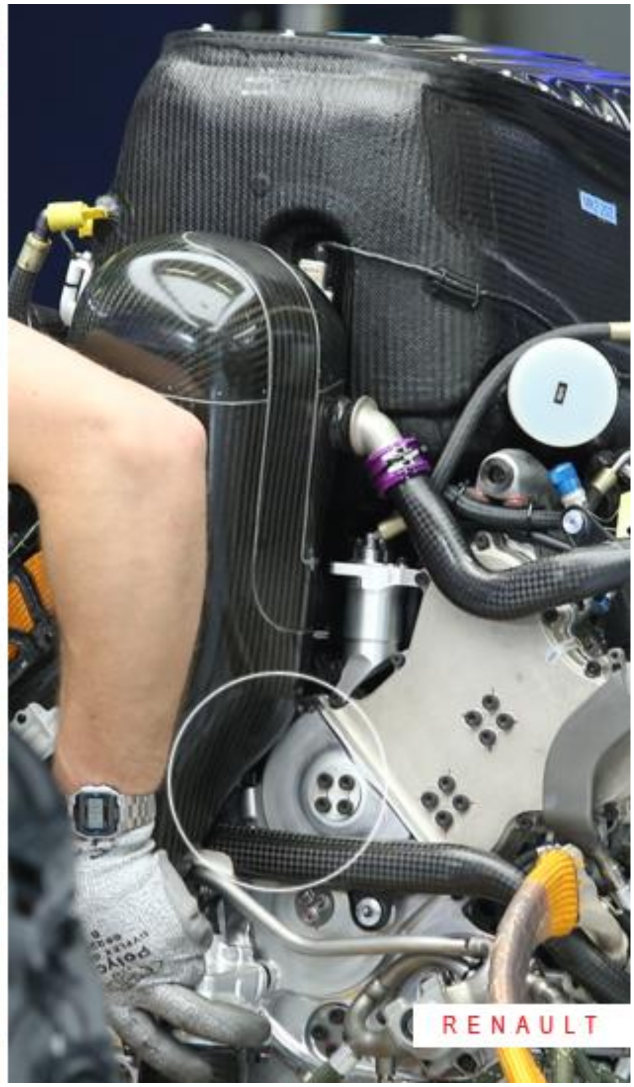
Renault's approach is a stark contrast to Mercedes' split-turbo installation that has the compressor placed at the front, while the turbine is positioned at the rear

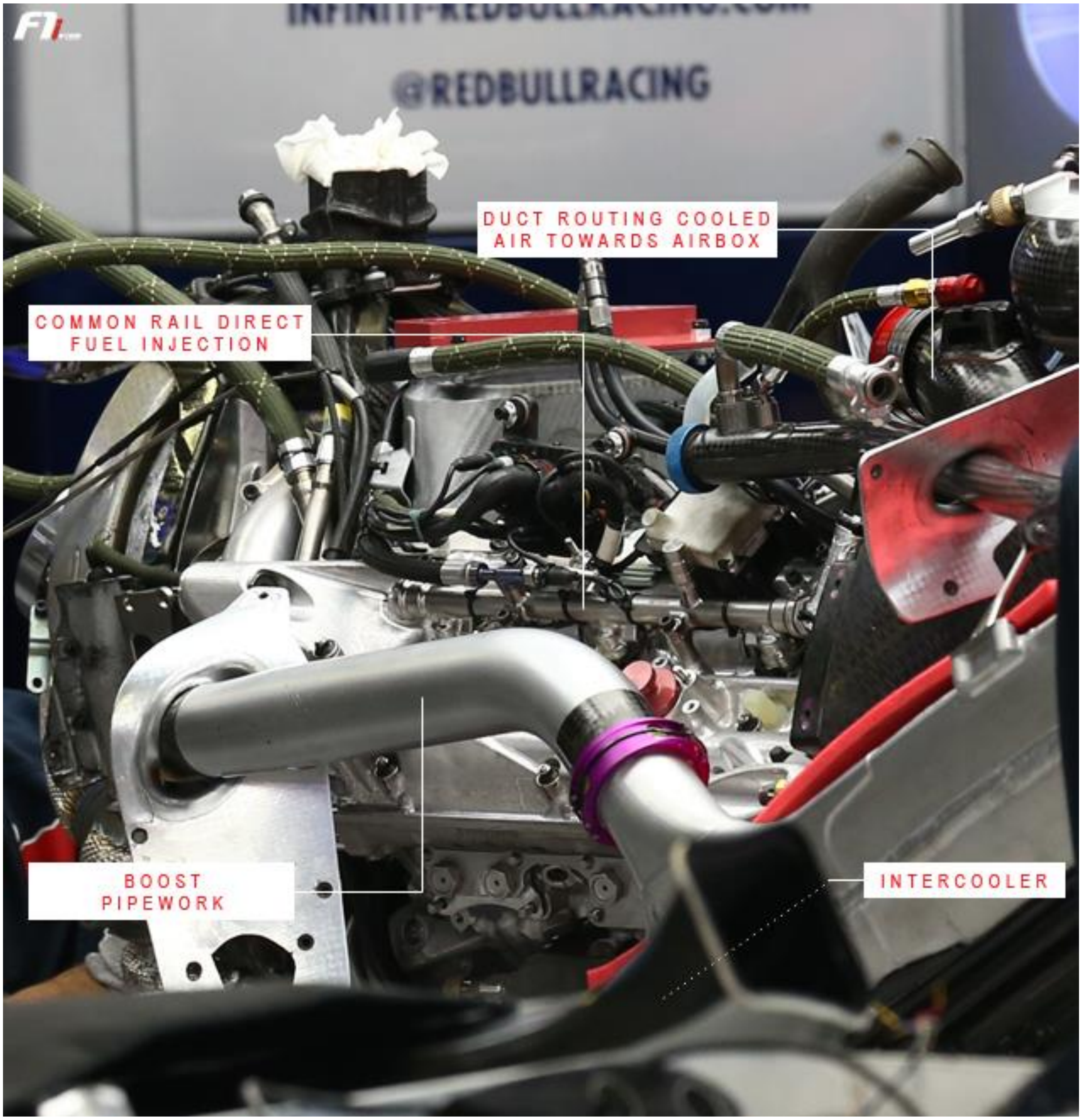
On the right-hand side of the picture, at the bottom of the engine, lies the MGU-K, which recovers kinetic energy under braking. The device extends into the oil pump, while one can also spot the orange three-phase electric cable that connects the MGU-K to the energy store.

The MGU-H, which absorbs power from the turbine shaft to convert heat energy from the exhaust gasses, is not visible on the images because it sits within the two rows of cylinders of the V6.


OIL TANK
PLENUM CHAMBER
OIL DUCTING
EXHAUST TAILPIPE
MGU-K
OIL PUMP
CABLE CONNECTING MGU-K & ENERGY STORE


COMPRESSOR
MERCEDES


RENAULT



PIPERWORK AND TURBO LAG

With the compressor located at the back of the engine, the Renault power unit architecture requires longer pipework than its Mercedes counterpart.

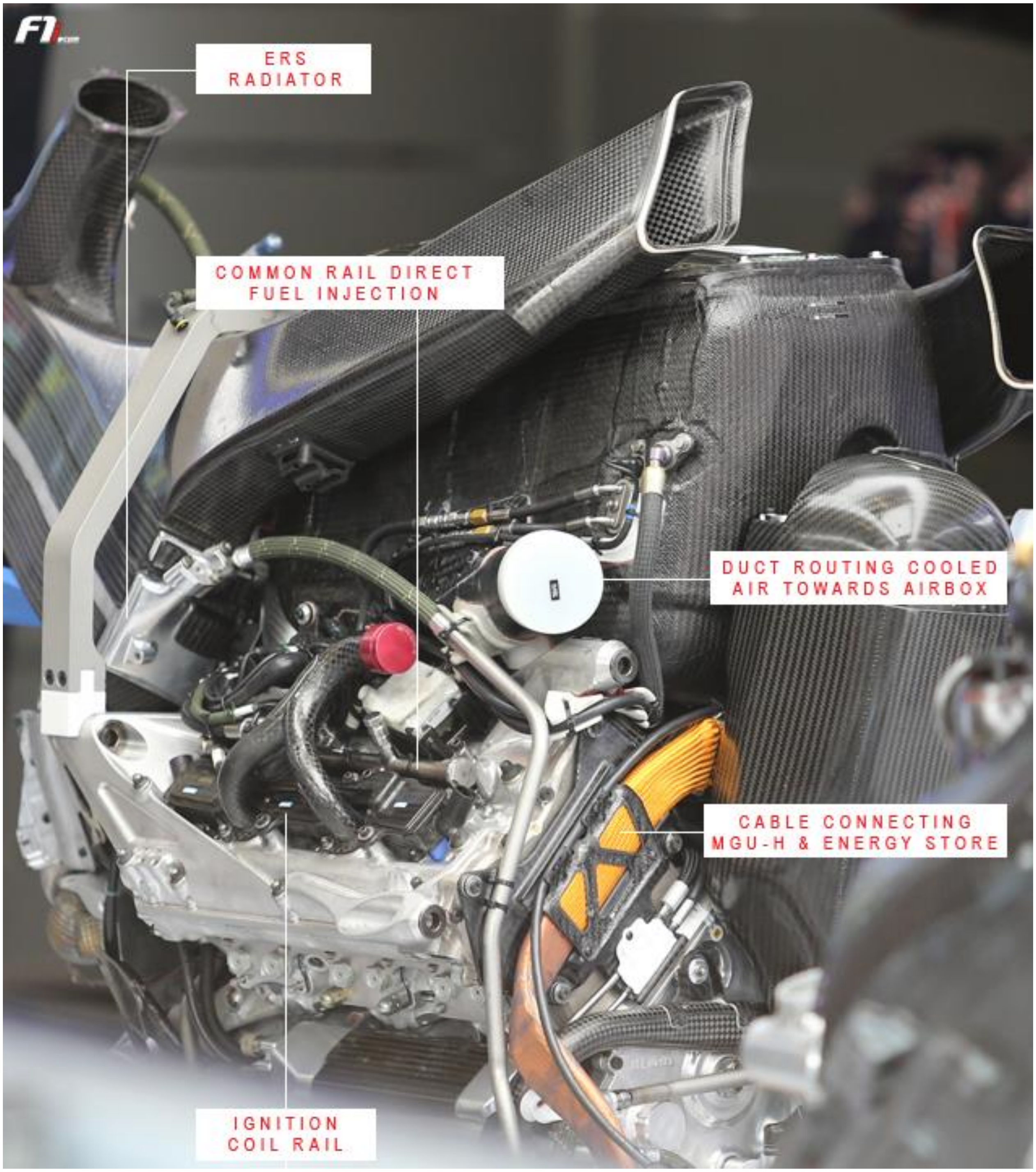
First, it takes some time for the air to go from the airbox to the compressor. Then, if you keep the PU106B as set up in the Mercedes W06 as your reference point, the compressed air has to travel over a greater distance to reach the intercooler.

As shown on the picture above, the big silver duct (the one with a purple pipe collar) is quite elongated. This theoretically means that more power is required to feed compressed air towards the intercooler. As a result, response time would be longer too, thus creating what is called “turbo lag”.

Red Bull has actually come up with a split-intercooler design, with one element featuring in each sidepod. Once the airflow has been cooled down, a specific duct is routing it towards the airbox, which works under pressure, and then towards the air intake plenum chamber.

Unlike Renault, Mercedes and Ferrari both have a single intercooler setup. However, the Silver Arrow’s intercooler has a central positioning and is lodged directly within the monocoque, while its Italian counterpart is placed within the Vee of the V6 engine, with both opting for such a layout in order to limit airflow resistance in the sidepods.

One can also easily spot the high-pressure common rail direct fuel injection system on the image above.



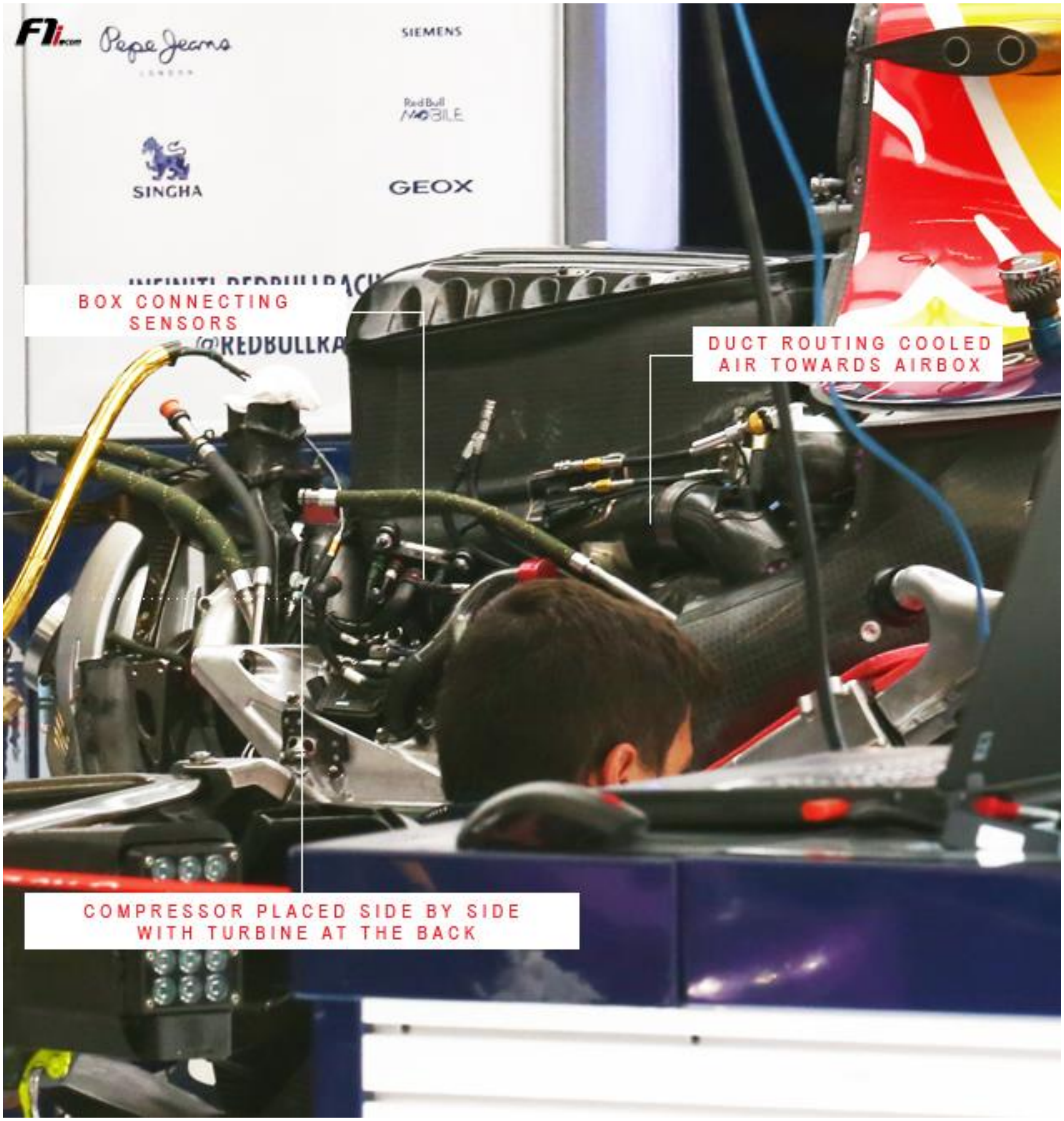
DIRECT FUEL INJECTION – PART I

Common rail systems usually feature piezoelectric injectors, which ensure fuel metering and injection timing to the cylinders with great precision.

Underneath is the ignition coil rail that comprises of three coils (one for each cylinder). The cylinder head is cooled down with a specific hydraulic fluid traveling through the red-sealed carbon tube.

The airbox logically sits at the top, and we can also notice the white-sealed pipe that in all likelihood feeds compressed and cooled down air towards the air intake plenum chamber. In order to accommodate Red Bull's split-intercooler design, an identical duct can be found at the same level but on the other side of the Renault power unit.

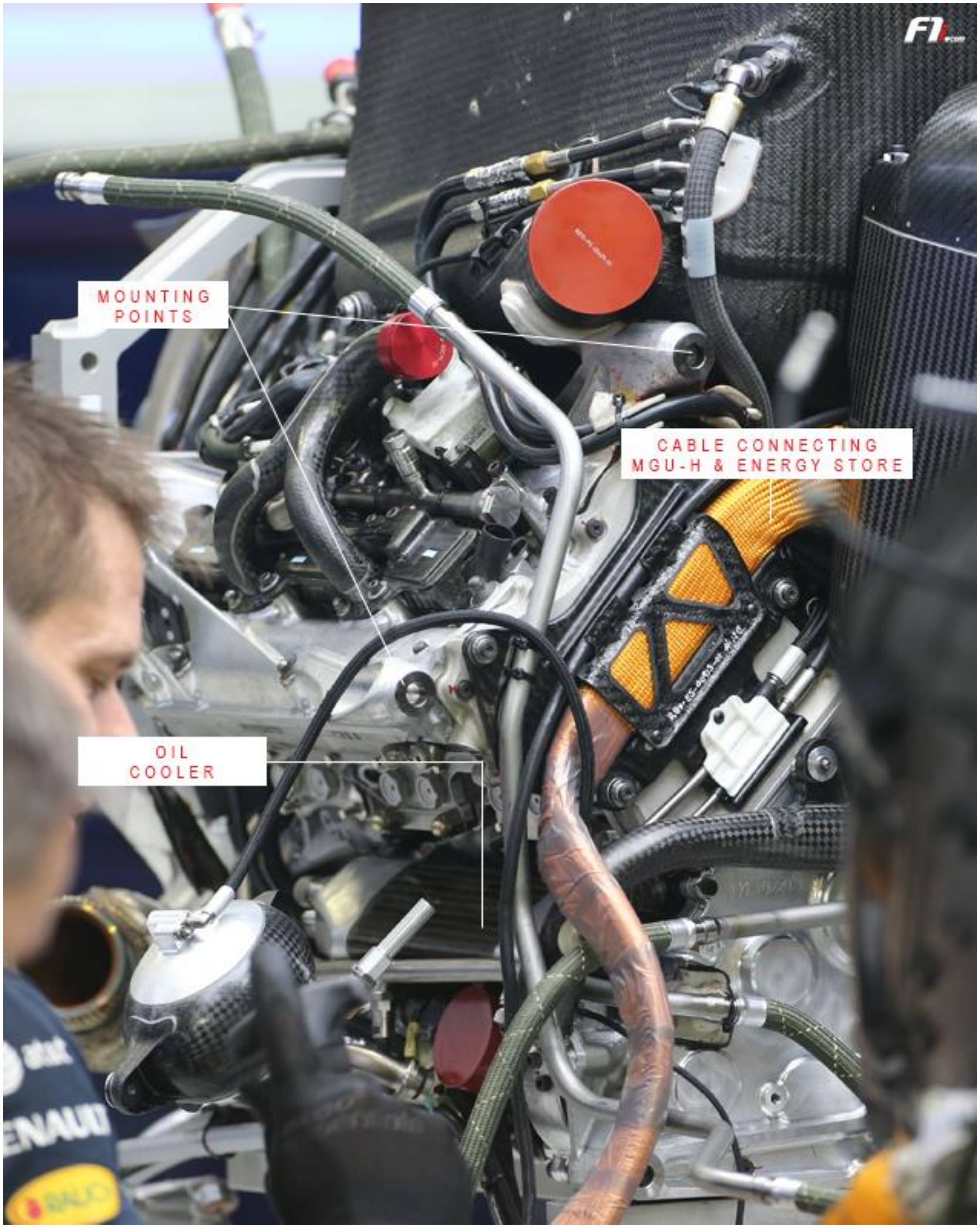
In all probability, the orange three-phase electric cable connects the MGU-H to the battery.



DIRECT FUEL INJECTION – PART II

Placed side by side with the turbine, the Renault compressor sits in an extremely hot environment with temperatures rising to 1000°C. This means that it needs more cooling than on the Mercedes engine, where the split-turbo installation has the compressor further away from the scorching heat released by the turbine. The knock-on effect is that Renault needs a bigger intercooler, which has a negative impact on the car's aerodynamics… at least in theory!

Indeed, power unit architecture alone does not define and determine overall engine performance. As clever as any design can be, perfect execution is needed, including in terms of electronics, in order to unlock the PU's full theoretical potential. Just look at Mercedes and Honda for instance. Both have gone for a split-turbo installation. One has been a resounding success; the other has yielded very little so far…



A CLOCKWORK ORANGE

At the bottom of the airbox, two high-pressure hydraulic pipes might activate the throttle valves, while we can also spot the mounting points that comply with FIA regulations.

The energy recovery systems (ERS) are made of five different components: the MGU-H, the MGU-K, the battery, a pair of control electronics boxes, and two cables.

The energy store, or battery, works on direct current, while both motor generator units (MGUs) are operating on three-phase alternating current. Therefore, there must be an electrical conversion between the two systems, and this is where the ERS control electronics (CE) come into play. There are actually two CE units – one for the MGU-K, another for the MGU-H – and both work the same way.

When one of the MGUs recovers energy, it sends AC power to the appropriate control electronics system via three high-current cables. These could well be the orange cables one can see on the image previous page.

A CONVENTIONAL EXHAUST MANIFOLD

As early as 2014, Renault went for a conventional manifold design to expel exhaust gasses and feed the turbine. Having initially followed another philosophy, Mercedes came up with a distinctive log manifold, before switching to a Renault-like installation this year. Each cylinder has its own exhaust, with the pipes then merging into the collector. On the picture above, the three openings are easy to see, which corresponds to the number of cylinders you have on each bank of the V6.

The length and diameter of the pipes, the collector angle, etc. all these elements have a critical impact on how well an engine can 'breathe'. The very same pipe can have several different diameters in order to create shock waves that resound back and help improve charging. Taking into account fluid dynamics and vibrations in the exhaust gas column, engineers eventually come up with complex, tangled and twisted pipe designs, which are optimised to reach better turbocharging efficiency.

With F1 engineers always eager to shed more weight off their cars, any exhaust manifold is made out of thin metal sheets. However, this solution increases heat loss, hence all engine suppliers wrapping up their exhaust pipes in a kind of insulating blanket (see picture) in order to maintain heat in the manifold and foster the expansion of gases.

Renault Sport F1 Director of Operations Rémi Taffin recently told **F1i** that Viry had mostly focussed on re-designing the combustion chamber, as well as reviewing the inlet and exhaust systems on its power unit. Indeed, the internal combustion engine (ICE) remains the biggest source of power and the cardinal element in the performance cycle.

"The ERS and battery are obviously very important and must work flawlessly for us to perform, but these components are not actually generating performance in the first place," he said. "It all starts with the ICE."

8. Under the Skin of the Front-Running 2015 F1 Cars

[Source: http://www.f1i.com – Nicolas Carpentiers]

MERCEDES: THE THEORY OF EVOLUTION

Formula One's relentless pace of development never stops. When time came to design their 2015 challenger, teams and engine manufacturers alike had already drawn valuable lessons from their first campaign with the new hybrid power units

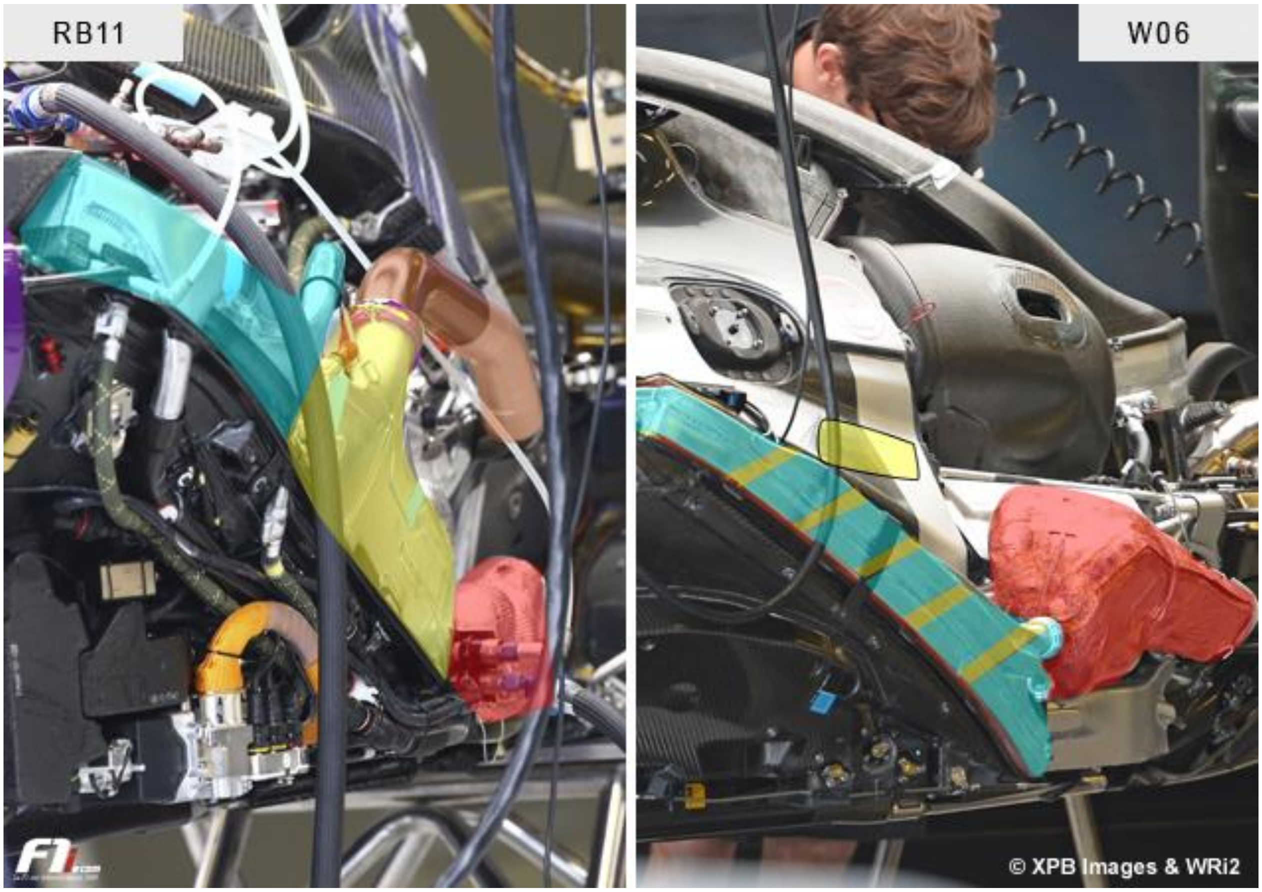
While the sport's technical regulations have remained pretty stable over the winter, V6 engine development is allowed (when V8s were totally frozen). Meanwhile, chassis engineers have been able to make bolder technical calls in an effort to unlock more performance, including the all-conquering Mercedes squad.

After all, Charles Darwin believed in the survival of the fittest and the most adaptable to change. And he knew a thing or two about evolution.

As shown on the two images above, Mercedes has dropped its trademark log manifold – a key feature on last year's W05 – to go for a more traditional exhaust installation on its latest design (see both designs in red).

The insulating walls (see dark blue arrows) are back while the cooler's shape (see blue outline) has not changed much either. However, the airbox, which feeds air to the engine, is significantly bulkier (see in green). This has probably been made with a view to housing the variable trumpets, as permitted by this year's technical regulations.

One can notice the package's overall neatness as well as the finely crafted electronic components, which can only hint at optimum integration on the W06 Hybrid.

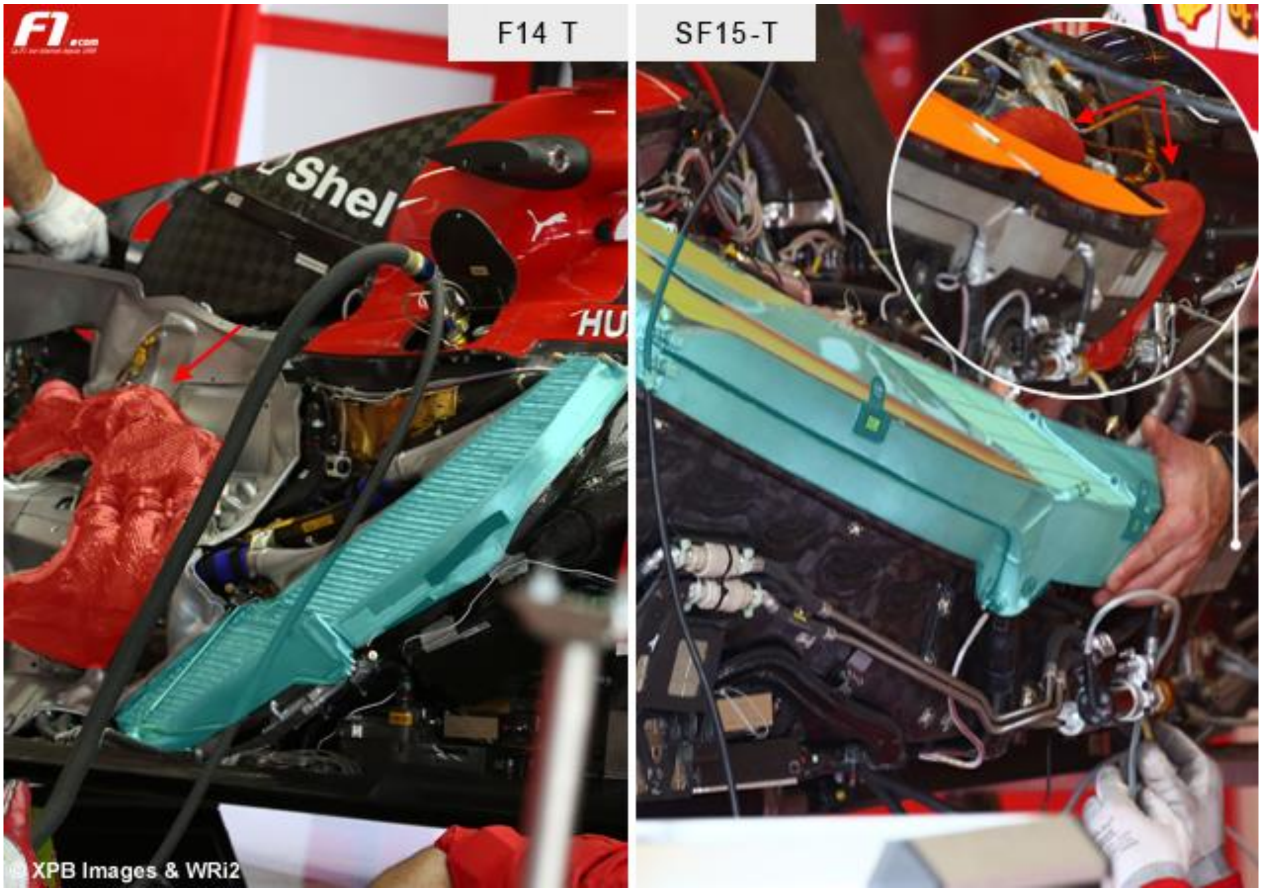


MERCEDES-RED BULL: A DIFFERENT INTERCOOLER INSTALLATION

The Mercedes intercooler cannot be seen on the right picture above because it has been placed directly within the car's chassis, in front of the ICE and near the compressor (basically in the yellow area). This installation requires less pipework, which in turn helps reduces the turbo lag phenomenon, clears the sidepod inlets, and limits internal airflow resistance.

The reigning world champions are the only team that uses an air-to-water intercooler (which is a more compact assembly than its air-to-air counterpart), with the water being cooled down via a specific radiator located in the left sidepod.

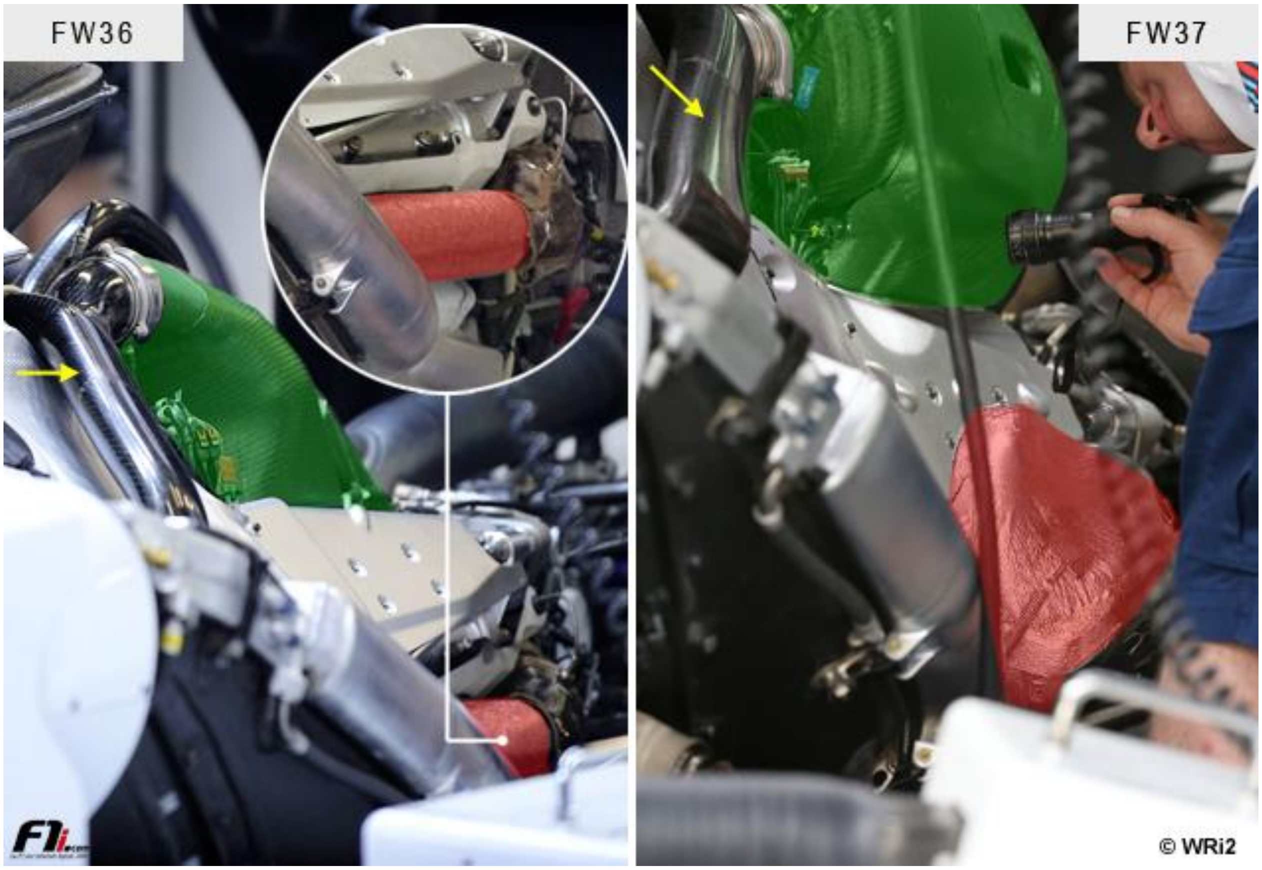
By contrast, the intercooler (in yellow) and the other coolers (in blue) are placed next to each other and inside the RB11's sidepods at Red Bull-Renault. The pipe (in orange) that links the intercooler to the engine inlet is quite long, while Renault's manifold installation sits at a lower level than the Mercedes exhaust assembly (see both elements in red).



FERRARI: A COMPACT EXHAUST MANIFOLD

Last year's F14 T had very long exhaust pipes that went upward and wrap around the internal combustion engine. Its successor features shorter and tighter ducts (compare both designs in red) that remain close to the car's underbody and reach the turbine from below. The latter has been lowered while the wastegate has been moved somewhere else.

The SF15-T's coolers are more horizontal and equipped with a clever louvre system that helps better direct the airflow, both on entry and exit of the radiators.

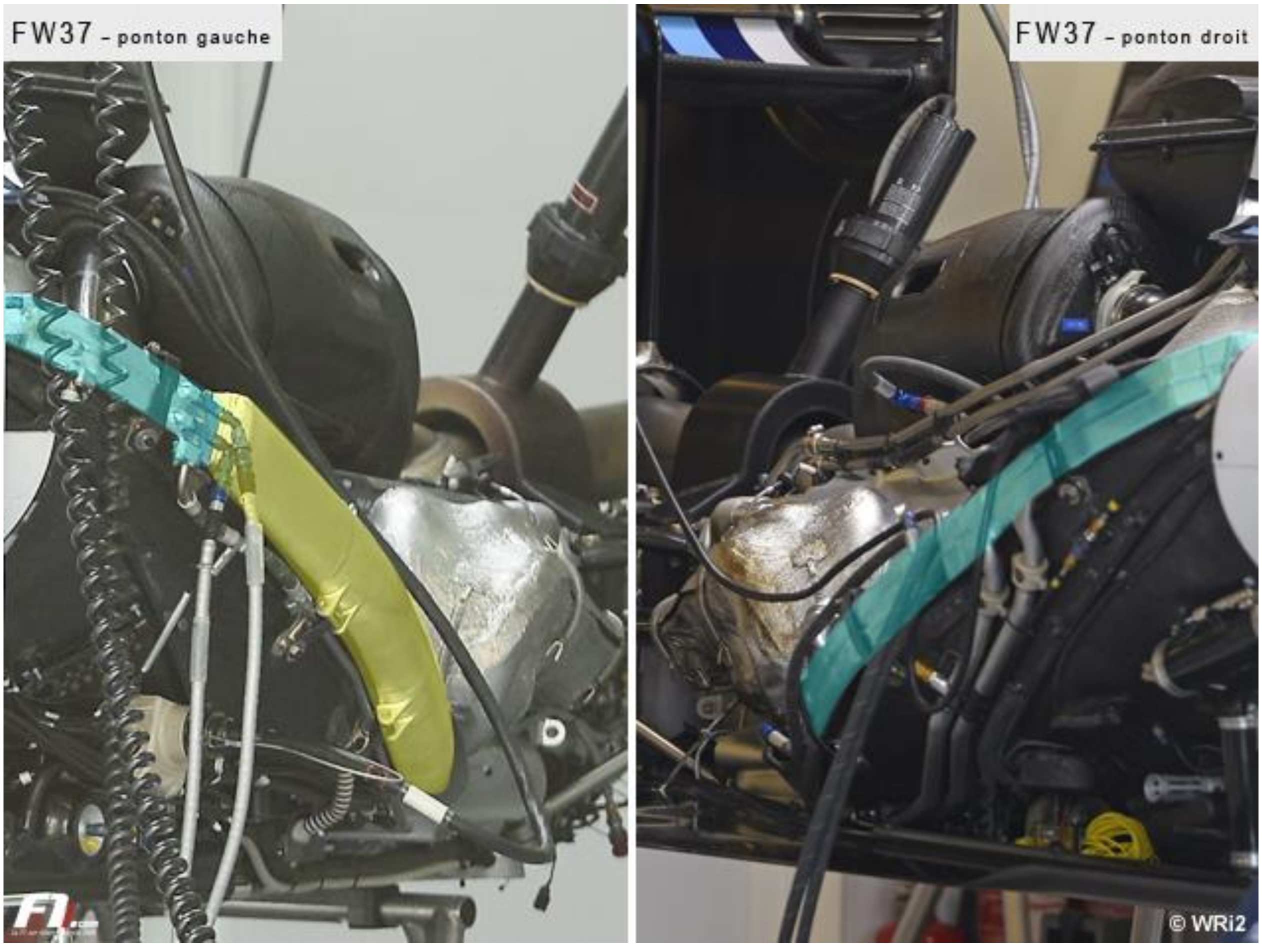


WILLIAMS: HARNESSING THE PU106B

Using the 2015-spec PU106B (compared to last year's model PU106A), Mercedes-powered Williams had to bring similar changes to its hybrid power unit installation as the defending champions. This means the airbox (in green) has been modified and the distinctive log manifold replaced with a more traditional exhaust design (in red).

Radiator volume has also been shrunk, which has enabled engineers and designers to trim down the car's sidepods. However, racing in Sepang-like sweltering conditions still requires more gills on the bodywork.

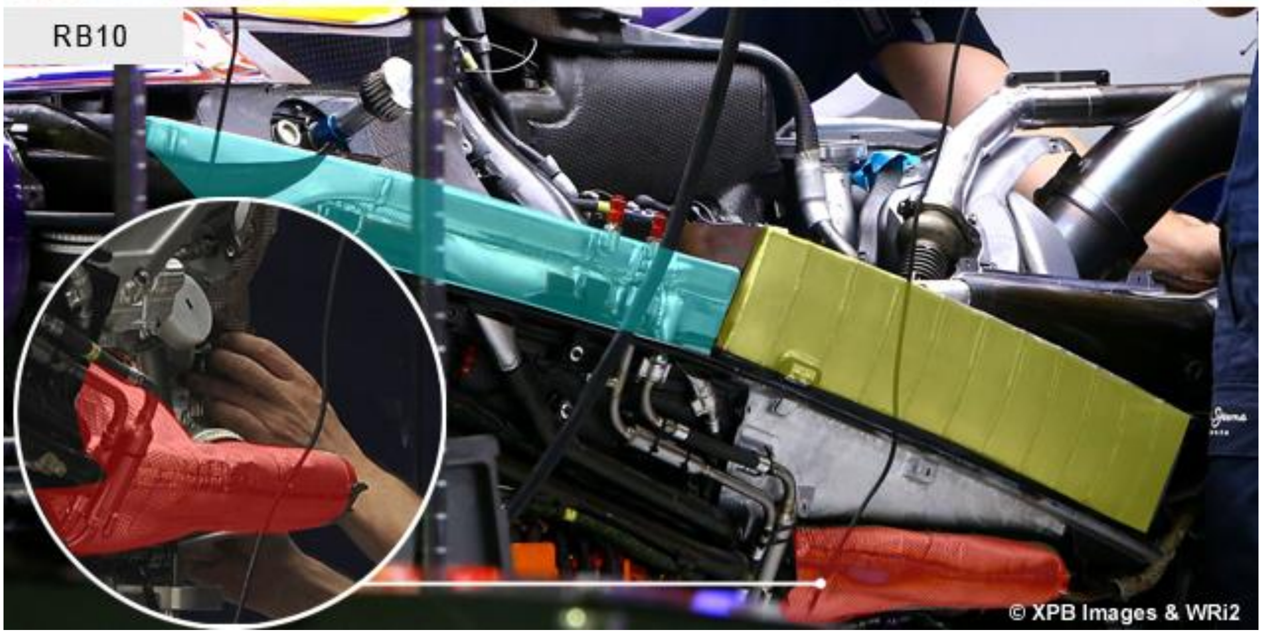
This said, the FW37's cooling system differs from the corresponding assembly on the W06 Hybrid, where the intercooler is lodged within the monocoque itself. Let's see how on the next page.



WILLIAMS: LEANING TO THE LEFT

All Mercedes customer teams use an air-to-air intercooler, which is placed inside one of their car’s sidepods. At Williams, the system (see the yellow outline) sits on the left alongside a small oil cooler, whereas there is a bigger radiator inside the right flank.

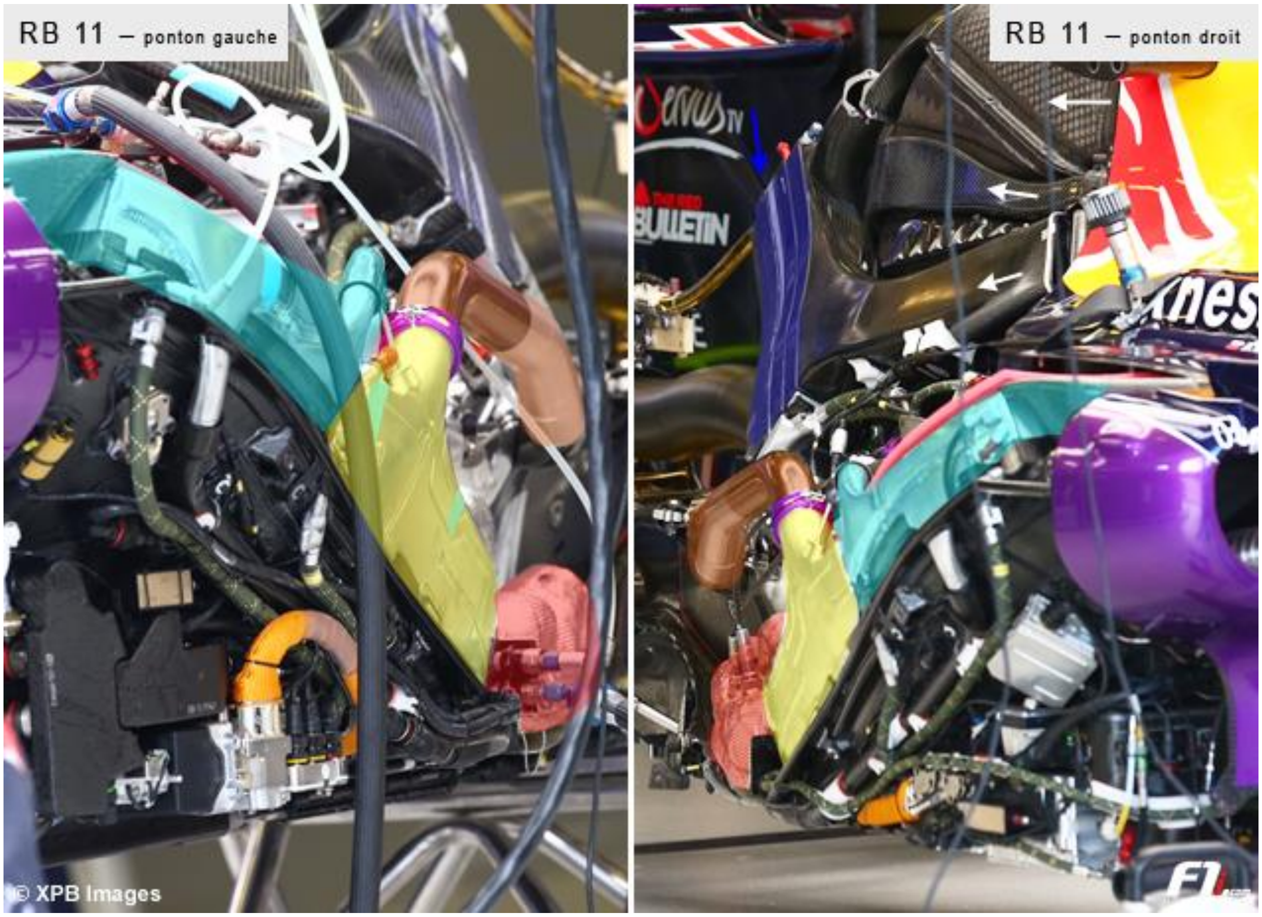
This asymmetrical installation means that Williams had to carefully assess the level of airflow resistance on both sidepods to ensure optimum car balance.



RED BULL-RENAULT: GOING FOR A SHORTER, MORE VERTICAL DESIGN

On last year's RB10 (see bottom picture), the radiator (in blue) and the intercooler (in yellow) were quite cumbersome and had been placed almost horizontally, stretching from the cockpit to the gearbox. This meant that the exhaust manifold (in red) sat just underneath the intercooler, which was not great in terms of temperature. However, the compressed air only had a short distance to travel before reaching the intercooler.

In order to design this year's RB11, Red Bull engineers have somehow taken inspiration from their Toro Rosso colleagues and followed their 2014 solutions: the radiator and the intercooler have both been diminished. This has helped clear the back of the chassis and place the exhaust pipes behind the intercooler instead of beneath.

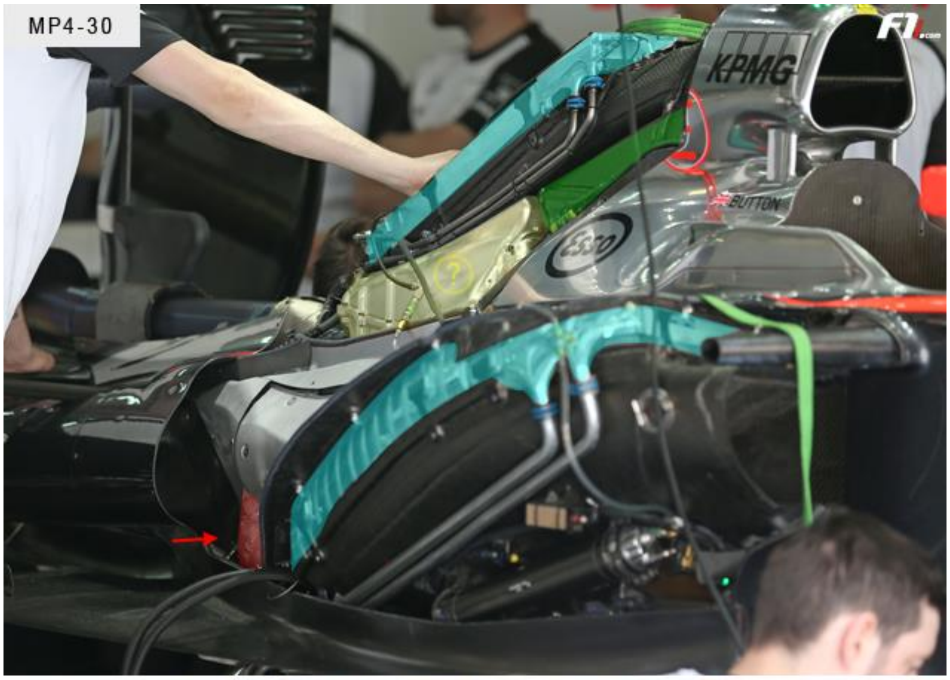


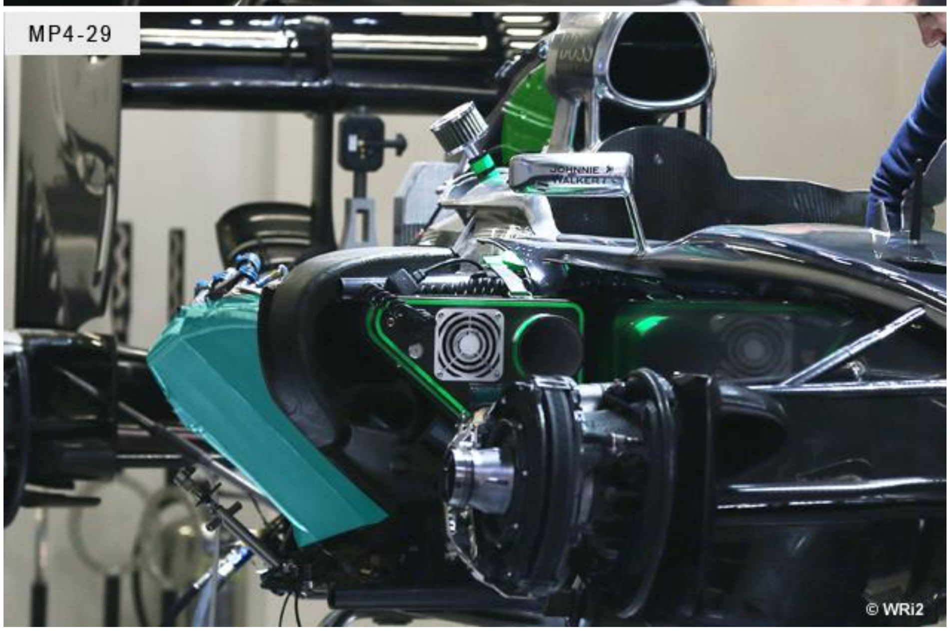
RED BULL: IT'S ALL ABOUT SYMMETRY

Symmetry between the left and right sidepod is an essential aspect on any F1 car. Indeed, the slightest difference will result in the car being unbalanced. Radiators do not have to be exactly identical on each side though (remember the Williams). What really matters is making sure internal airflow resistance has been weighted and equalised across the car.

Red Bull has come up with a split-intercooler design, with one element featuring in each sidepod. As shown above, both flanks are symmetrical in an effort to minimise any drag or aerodynamic performance differential on the car.

Finally, the RB11 has an imposing water cooler mounted on top of its transmission (see the dark blue arrow), which is fed by one of the air intake's three ducts. This aims at shortening the radiators and bringing them forward.





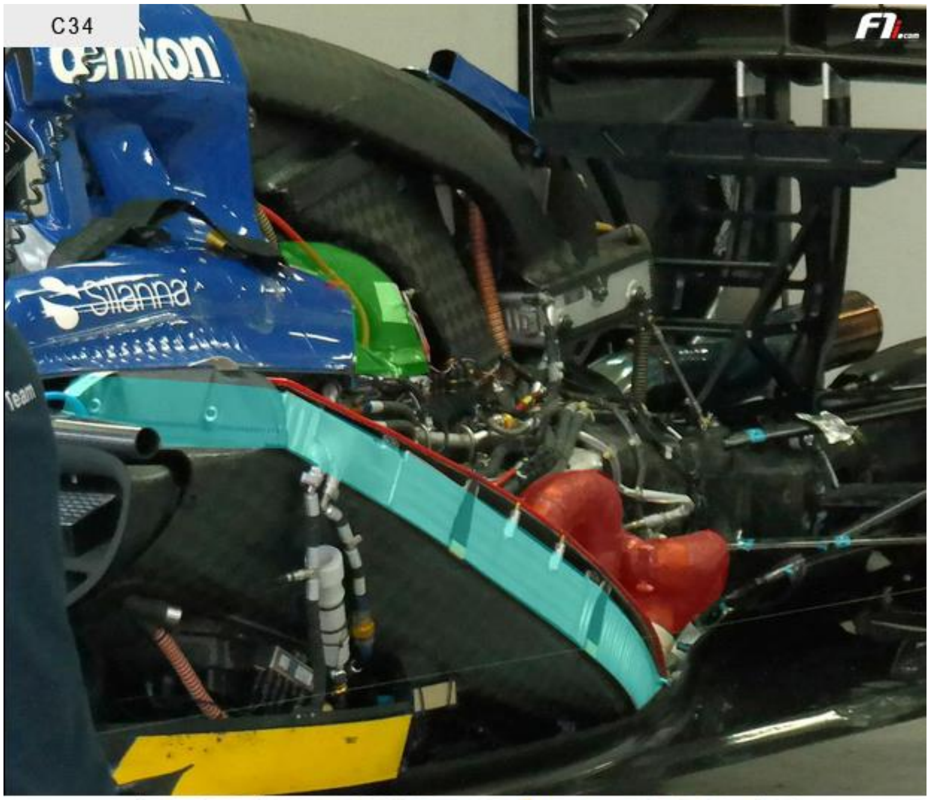
McLAREN: INNOVATIONS AMID QUESTIONS

Last year's Mercedes-powered MP4-29 had oblique-positioned coolers. Radiators now have a flatter, more traditional placement on the McLaren-Honda MP4-30

Woking's latest charger still features innovative solutions like having a small cooler directly attached to the air intake's superior duct. Indeed, the airbox is split into a pair of ducts. The top one feeds cooling air to the aforementioned radiator, which is actually an ERS cooler. The second duct channels air towards the compressor of the V6 internal combustion engine.

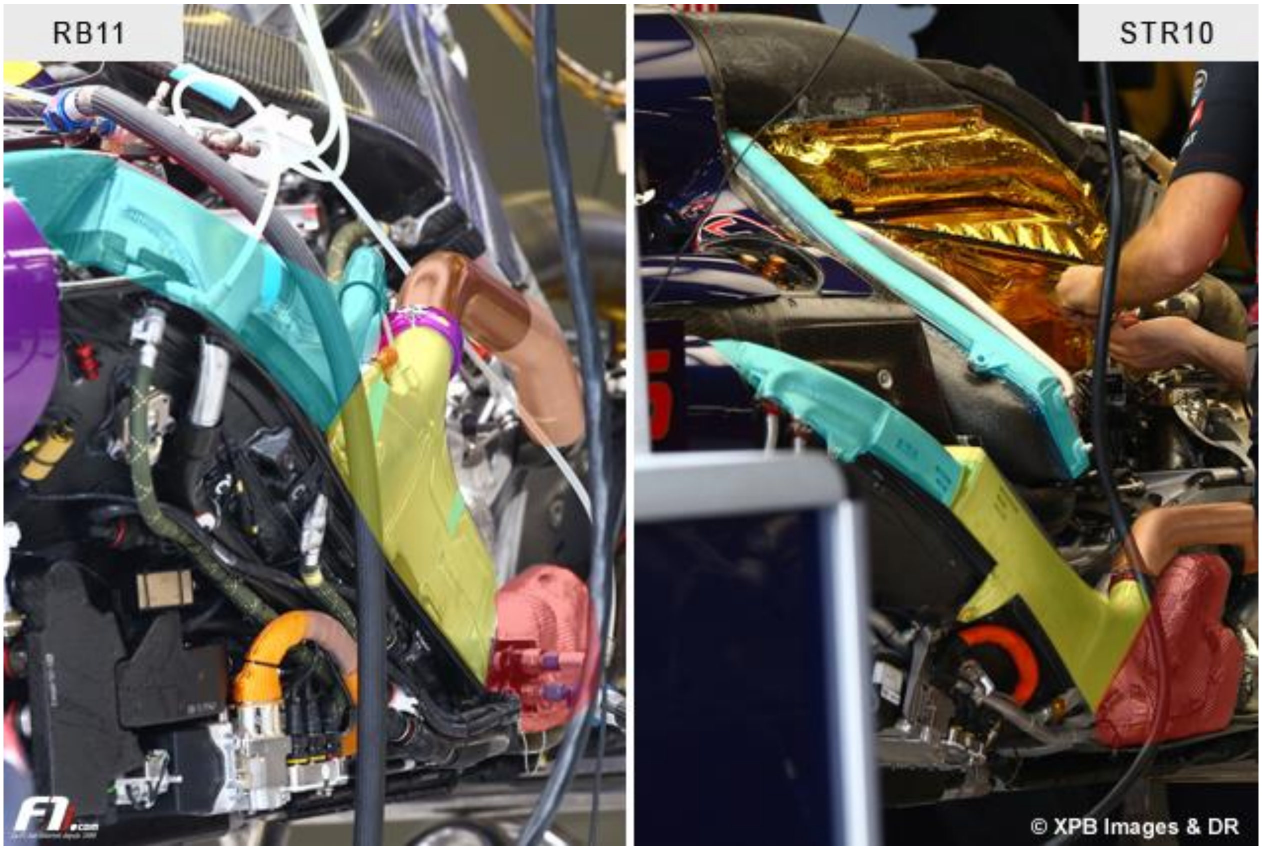
The intercooler's exact location remains unknown for the moment. Has it been placed inside the left sidepod? Perhaps above the ICE (see gold area)? We'll have to wait for extra pictures to find out.

One can actually see part of Honda's exhaust manifold installation (see red arrows). Its positioning is similar to Renault and Ferrari's designs (Mercedes' exhaust pipes are higher up, as seen on the very first picture).



SAUBER : HORIZONTAL

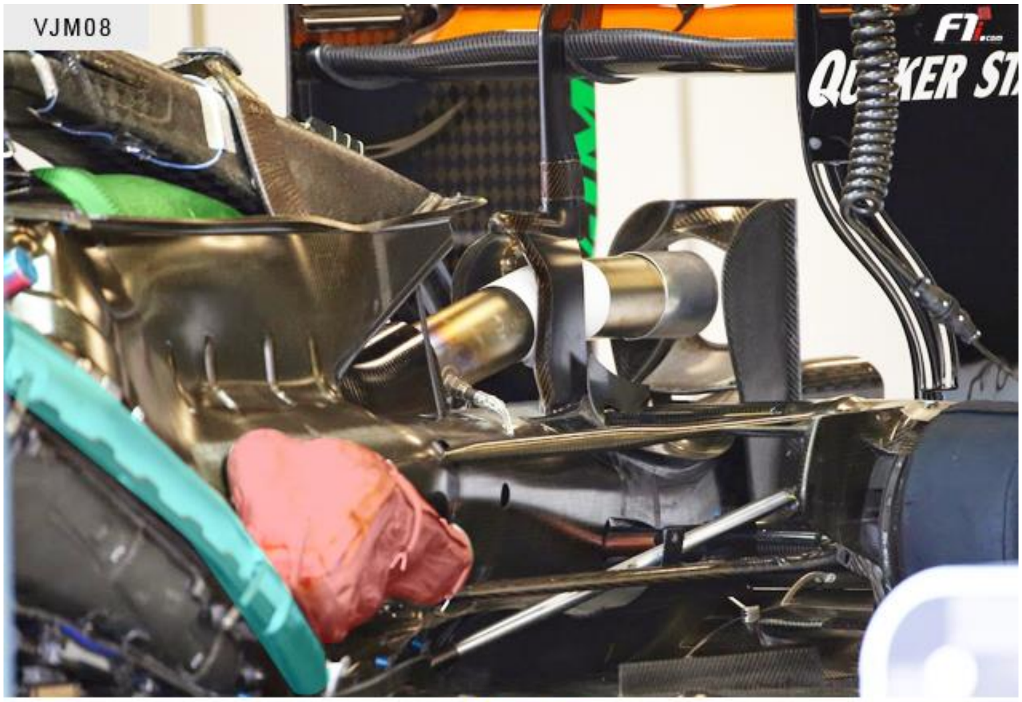
Powered by the Ferrari 059/4 engine, the C34 is equipped with exhaust pipes (red) shorter and lower than its predecessor, as the Ferrari SF15-T. Its radiators are also adopting a shape (square) and a position (horizontal), more classical.

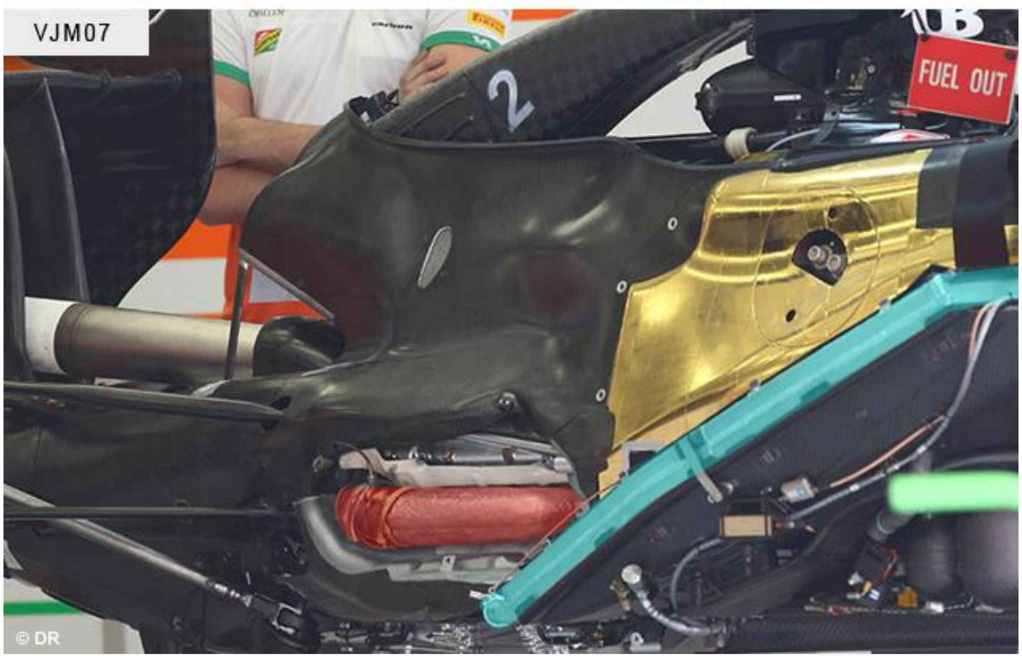


TORO ROSSO : ORIGINALE VERSION

The installation of the V6 Renault and its devices is quite similar to the Red Bull (left) and the Toro Rosso (right): radiator (blue), exchanger (yellow) and pipes (red) are located in the same way on the STR10 and RB11.

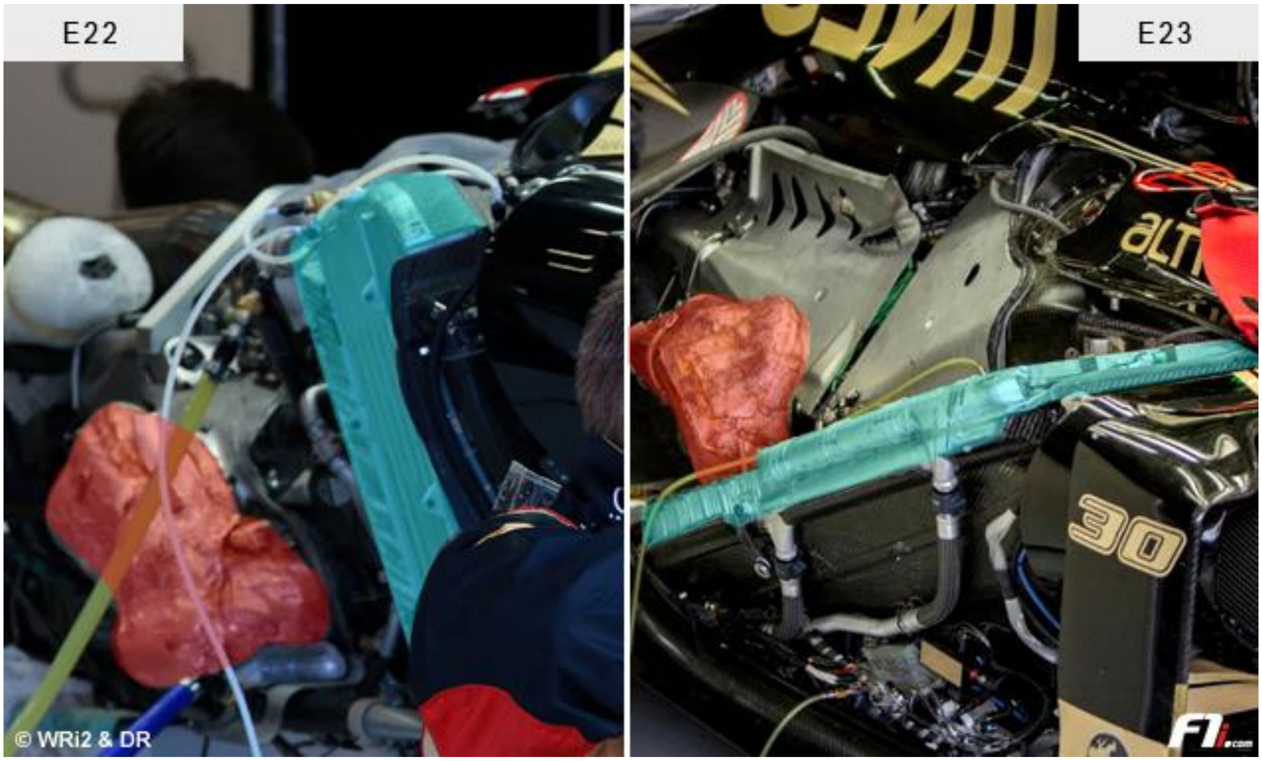
Two differences, however: the presence of an oil radiator on each side of the air intake on the Italian car, and the height of the duct leading to the exchanger, highlighted in orange (it is low on the Toro Rosso and high on the Red Bull, far from the hot exhaust).





FORCE INDIA : CHANGE IN CONTINUITY

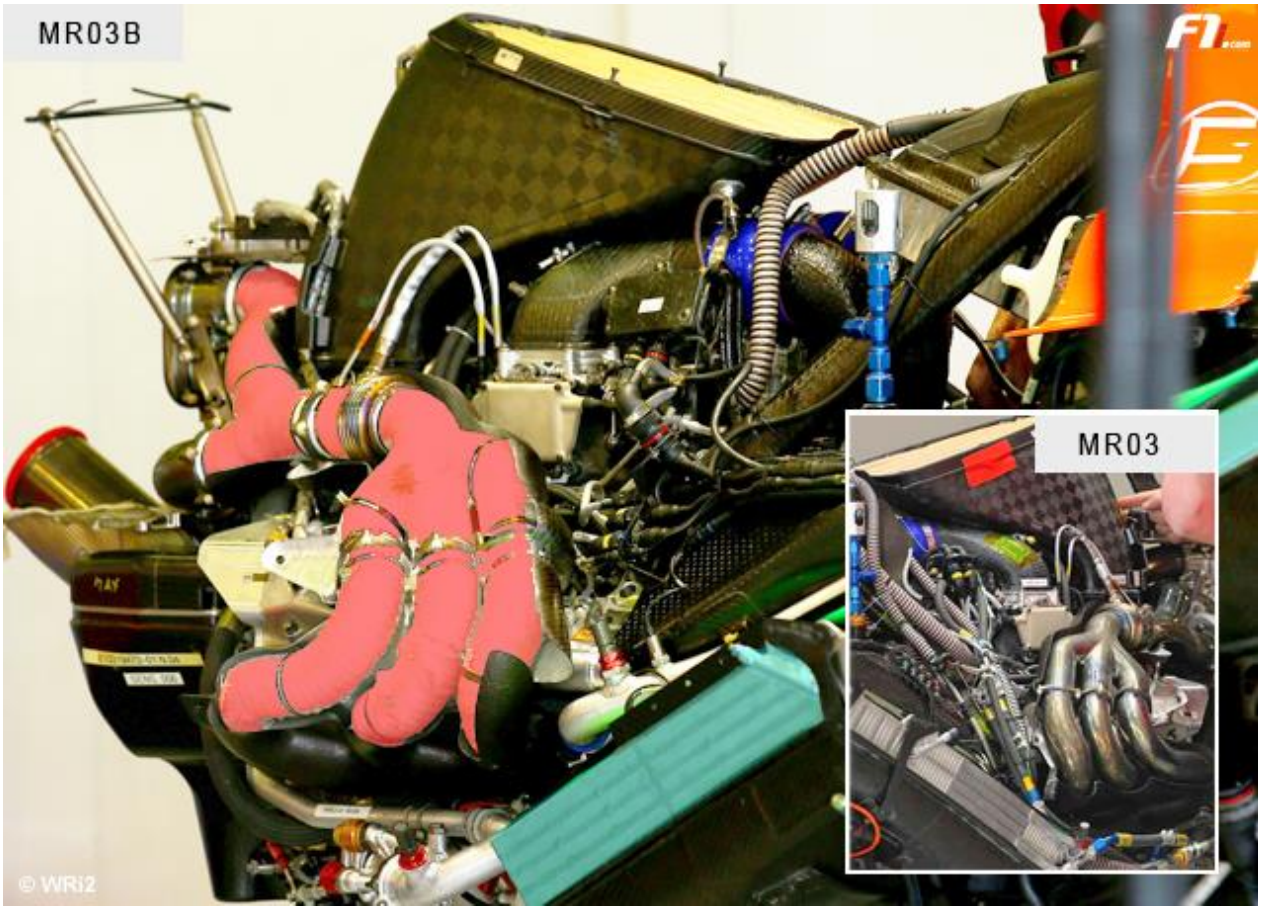
The VJM08 shows the same changes as other cars powered by the V6 Mercedes PU106B on the installation of the hybrid propulsion: an air box (green) more cumbersome, standard tubing "spaghetti" instead of a single collector (in red).
Force India engineers have maintained a shroud covering and installed the exchanger in one of the side pods (like Williams).



LOTUS: BACK TO CLASSICISM

Switching from the Renault V6 to the six cylinder Mercedes, Lotus has reviewed the implementation of the radiators on the E23. Like Sauber and McLaren, Enstone abandoned the vertical position in favor of a horizontal installation.

The team found conventional tubing, new for Mercedes this year, which already existed in the Renault V6.



MANOR: COPY

Manor using the same chassis as last year there is no difference between the MR3 and MR3B on engine installation.

Always equipped with the old V6 Ferrari 2014 (059/3), the British car retains the "climbers" tubing views last year.

9. How Does the 2015 Engine Unfreeze Work?

[Source: http://www.f1i.com – Nicolas Carpentiers]

"Why simplify things when you can make it complex?" This sounds like a fitting motto to define Formula One as the pinnacle of motorsport often finds ways to come up with intricate and (unnecessarily) complicated regulations.

With last year's power unit (PU) homologation date set to 28 February 2014, Mercedes, Renault, and Ferrari could not develop their hybrid turbo V6 engines during the season. Only exceptions were if the planned upgrades targeted reliability and/or safety improvement, or helped save costs.

Despite both Viry and Maranello bitterly complaining against what they perceive to be an unfair engine freeze, the new regulations have actually always allowed for power unit developments. These just needed to be brought in 2015, and this is why factories in France and Italy have been busily working all winter in order to close the gap to frontrunner Mercedes.
It was initially implied that all power unit suppliers once again would have to homologate their 2015-spec hybrid turbo V6s before the opening grand prix in Melbourne. However, Ferrari and Renault quickly pointed out that the latest Formula One technical regulations did not mention a specific date. Both challengers wasted little time in exploiting the loophole and had the FIA cave in to allow in-season development, with new Ferrari president Sergio Marchionne hailing the decision as a "first victory".

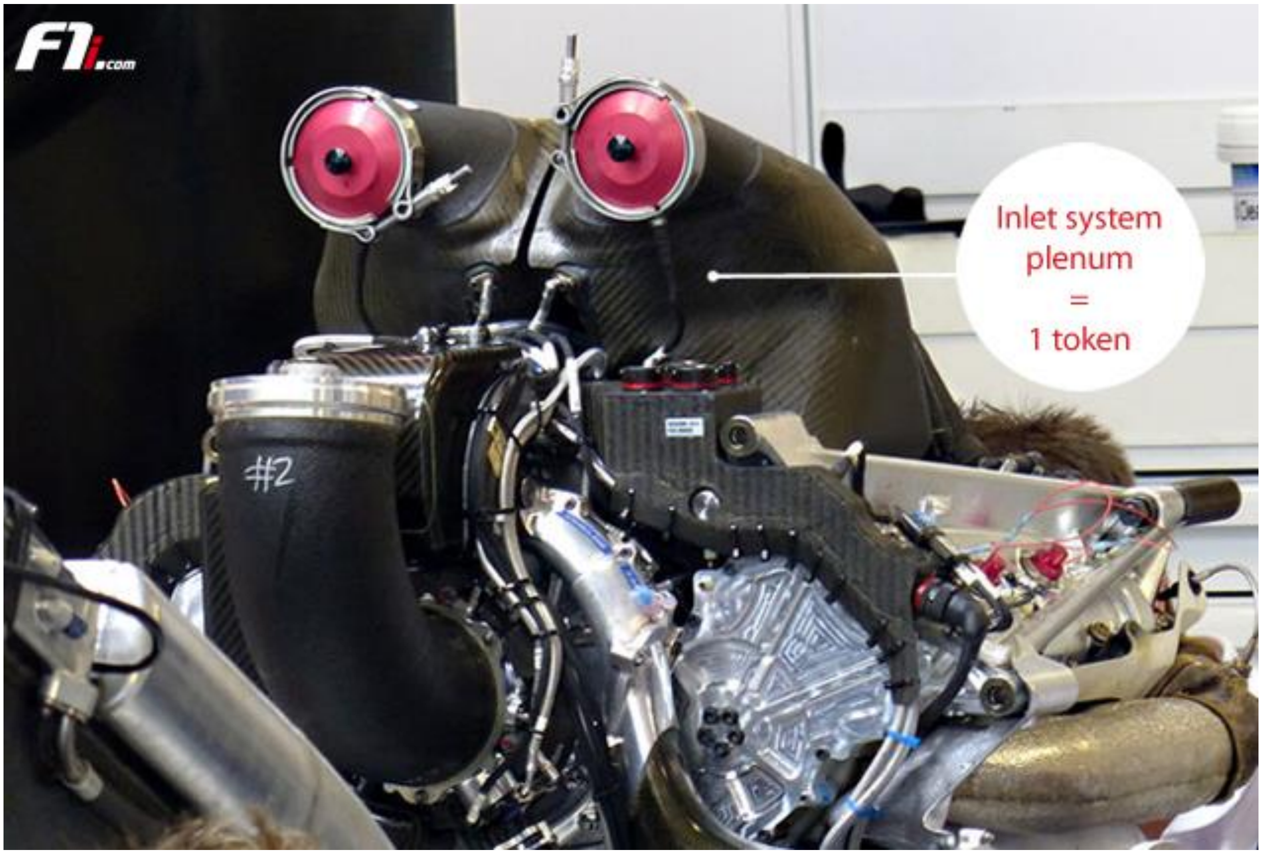
This does not mean Ferrari et al will have ***carte blanche*** to improve their power units though. Indeed, they can only do so within a specific development frame set by the FIA. As winter testing nears, how much leeway do manufacturers actually have?

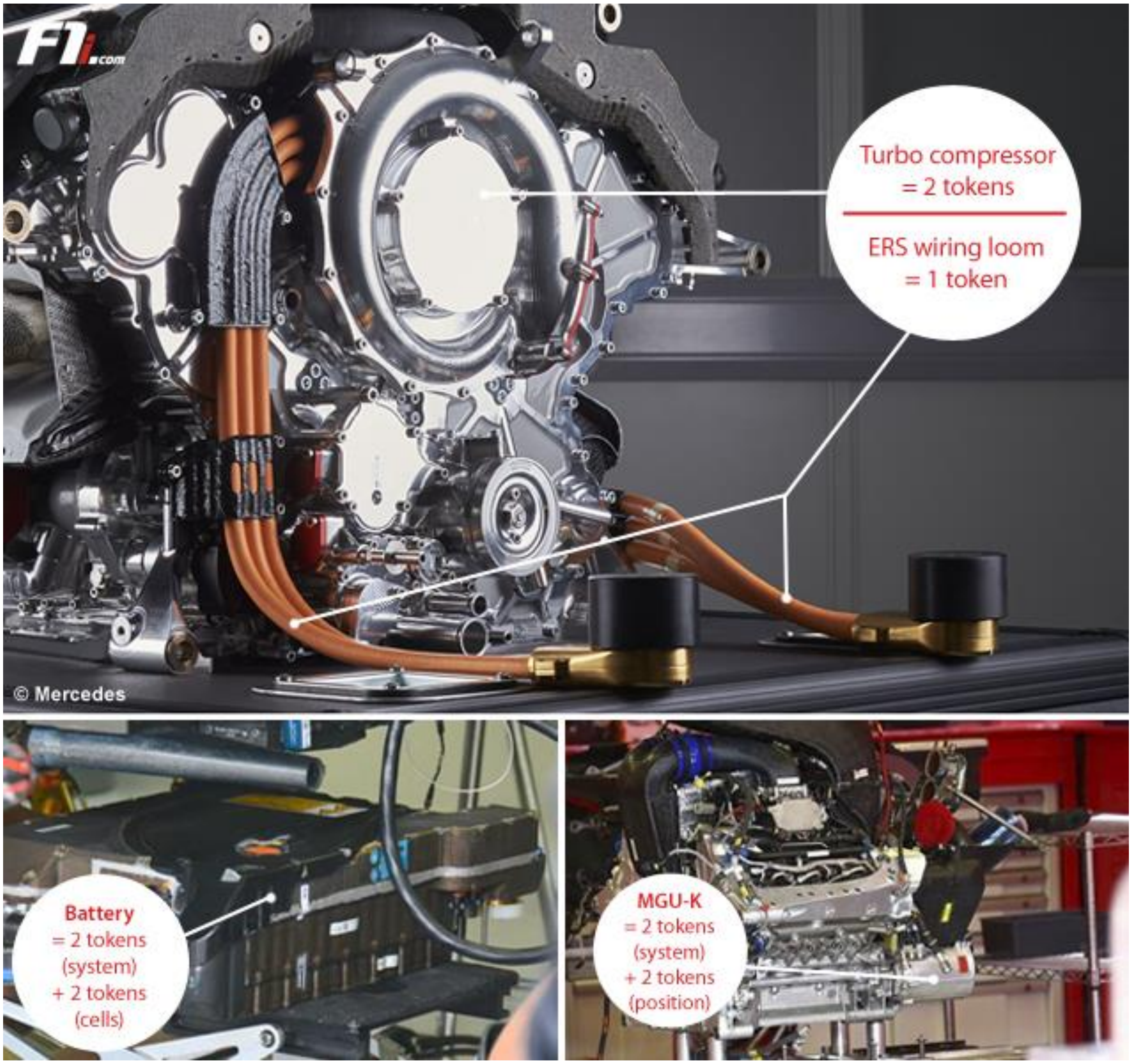
Increased restrictions

In an attempt to save costs while still allowing updates, the FIA has designed a token system whereby room for engine development will gradually decrease. Indeed, only a certain number of PU components can be modified every year, with the amount shrinking from one season to another.
In appendix 4 of its 2015 Formula One technical regulations, the FIA has broken down the new power units into several categories, which encompass functions like "combustion", "ignition system", "valves", "upper/lower crankcase", "MGU-H", "MGU-K", etc.

Each individual component was 'weighted' between one and three, depending on their importance. For instance, both the compressor and turbine inside the turbocharger are worth two tokens, while the exhaust flanges going from the engine to the turbine inlet only weighs one. Similarly, tweaking the oil pump will cost you one token whereas modifying the timing belt requires three. The whole power unit is ultimately made up of 66 tokens.

However, five of these have been completely frozen ahead of 2015, and spread across the three following categories: the crankshaft (two tokens), the air valve system (one), and some aspects of the upper/lower crankcase, including cylinder bore spacing, deck height and bank stagger (two). This represents around 8 per cent of the entire hybrid turbo V6.





A game of two halves

All the other areas of the power unit can be tweaked, albeit in limited proportions. If 61 tokens are still potentially available to spend, official rules will restrict each engine supplier to 32 in 2015, namely around 48 per cent of the components. It is then up to Mercedes, Renault, and Ferrari to decide which parts of their power units they want to improve first and foremost. For instance, Renault and Ferrari could theoretically use their 32 allocated tokens in order to adopt the German behemoth's design, which separates the compressor from the turbine, and monitor the effects of such a technology shift.

Looking from the opposite perspective, 'frozen' engine parts include the mandatory FIA restriction on three categories (five tokens or 8 per cent) as well as all the components left out of development by each PU supplier. Therefore, it will be quite interesting to see where Mercedes and co choose not to spend these remaining 29 tokens (approximately 44 per cent of the power unit).

As mentioned earlier, the number of usable tokens – namely the scope for each constructor to review their engine – is bound to decrease over the years. From 48 per cent in 2015, only 38 per cent of the power unit can be changed next season, dropping to 30 per cent in 2017, then 23 per cent, and finally a mere five per cent in 2019 and 2020.

If every engine supplier does enjoy some leeway entering the 2015 season, they are still restricted in how they can improve their power units. Challengers Renault and Ferrari have to play catch-up and will therefore spend their tokens accordingly, while Mercedes can focus on other areas in a bid to further enhance its already impressive hybrid turbo V6. What's more, the three 2014 contenders still need to have their power units homologated before the season kicks off Down Under mid-March. Then, they can use what's left of the 32-token allocation as they see fit in order to fine-tune their hybrid turbo V6s throughout the year.

The curious case of Honda

Newcomer Honda faced a very different situation ahead of 2015 as the Japanese manufacturer did not have yet to abide by the FIA token system and thus could push engine development as much as they wanted to. However, it was initially understood that Honda would have to homologate their power unit by 28 February 2015 and then race the same specification all year long, as per the existing manufacturers last year.

In other words, Honda and partner team McLaren would have not been able to benefit from the engine loophole and refine their turbo V6 during the season. The pair were quite aggrieved about the matter and quickly called for a meeting with the FIA to discuss power unit regulations. The consultation did yield positive results for Honda and McLaren as Formula One's governing body eventually backtracked and allowed the Japanese manufacturer to develop their engine over the course of 2015.

As for the number of tokens Honda will be granted this year, the FIA came up with the following consensus:

"As each of the four 2015 manufacturers will have an homologated power unit at the start of the season, we believe it would be fair to ensure that each of them enjoys equal opportunities for upgrades during the season," FIA Head of F1 Technical Department Charlie Whiting wrote in a letter sent to teams.

"We will therefore allow the new manufacturer [Honda] to use the same number of tokens that the other three [Mercedes, Ferrari, and Renault] have available to them, taken as an average of the three."

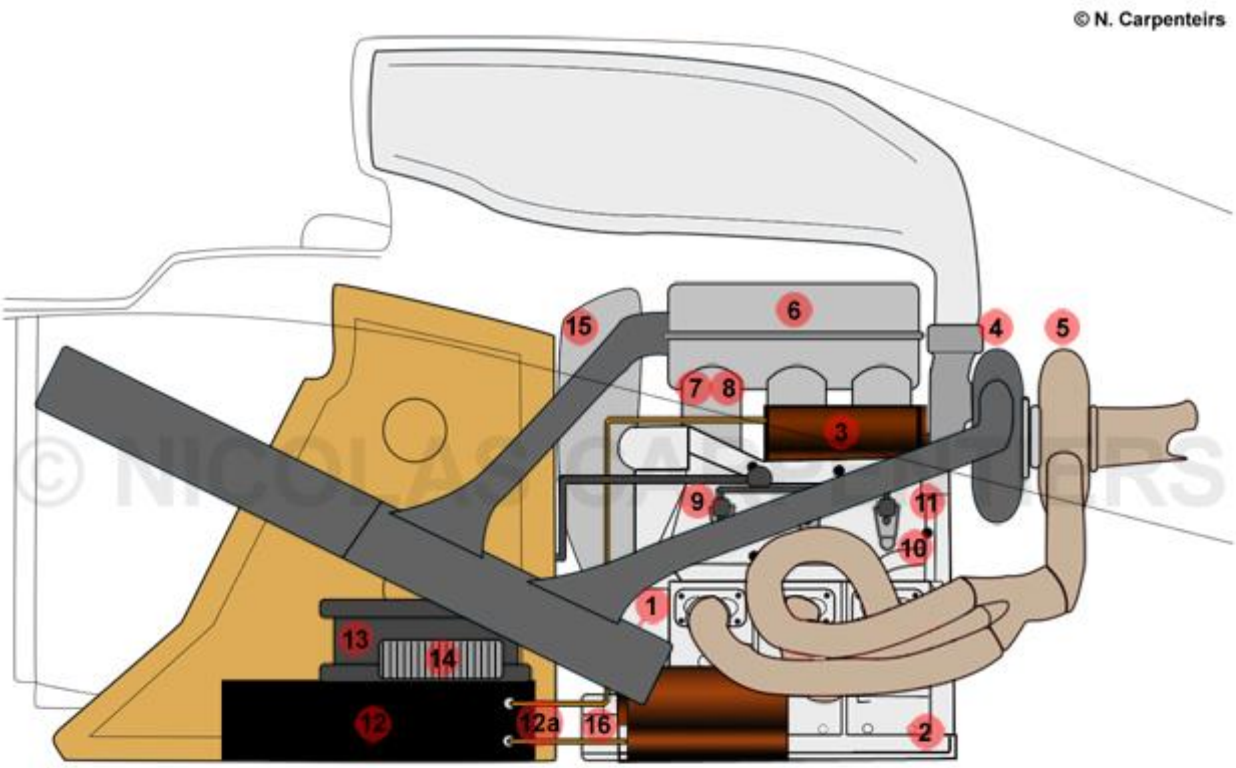
Whiting then gave an example to illustrate a ruling that, in typical F1 fashion, looked clear as mud at first.

"If the three 2014 manufacturers have eight, seven and five unused tokens respectively at the start of the season, then [Honda] will be allowed to use six during the season (the average rounded down to the nearest whole number)".

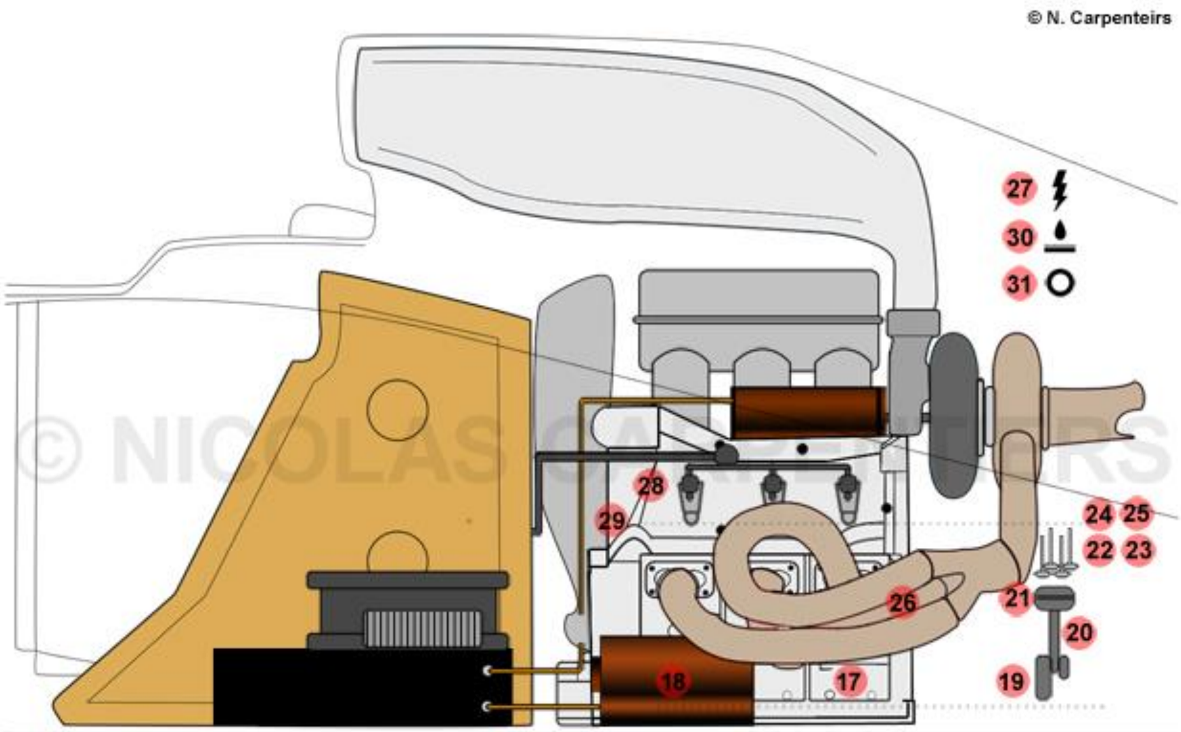
This latest twist in the on-going power unit saga further highlights Formula One's inherent turmoil at balancing cost-saving measures with attractive, open competition.

How much does each PU component weigh?

The following pages present a simplified list of the components of a hybrid power unit, along with their FIA token value.



Caption	Component	Weight
1	Engine water pumps	1 token
2	Oil scavenge system	1 token
3	MGU-H – Complete system	2 tokens
3	MGU-H – position	2 tokens
4	Turbocharger – Compressor	2 tokens
5	Turbocharger – Turbine	2 tokens
6	Inlet system – plenum	1 token
7	Inlet system – Trumpets and associated parts	1 token
8	Inlet system – Throttles and associated parts	1 token
9	Injection system	2 tokens
10	Ignition system	1 token
11	Cylinder head	2 tokens
12	Energy Store (ES) – Battery cells	2 tokens
12	Battery Management System (BMS)	2 tokens
12	ERS – Cooling/lubrication	1 token
12a	ERS – Wiring loom	1 token
13	MGU-H – Power electronics	1 token
14	MGU-K – Power electronics	1 token
15	Oil tank	1 token
16	Oil pressure pumps	1 token
16	All parts in which circulates oil under pressure	1 token



Caption	Component	Weight
17	Crankcase – cylinder bore spacing, deck height, bank stagger*	2 tokens
17	Crankcase – all other dimensions	3 tokens
18	MGU-K	2 tokens
18	MGU-K – position, transmission	2 tokens
19	Crankshaft – Crank throw, main bearing journal diameter, etc*	2 tokens
19	Crankshaft	2 tokens
20	Con rods	2 tokens
21	All parts defining combustion – Piston crown, chamber, etc.	3 tokens
21	Pistons	2 tokens
22	Valves	2 tokens
22	Valve drive	2 tokens
23	Pneumatic valve return system	1 token
24	Valve drive/camshaft – from camshaft lobe to gear train	1 token
25	Valve drive – Gear train	2 tokens
26	Exhaust system	1 token
26	Wastegate	1 token
27	Electrical system	1 token
28	Covers – cam-timing covers, cam covers, etc.	1 token
29	Ancillaries drive	3 tokens
30	Friction coatings	1 token
31	Sliding or rotating seals	1 token
	Total :	**66 tokens**

PU components that have been totally frozen by the FIA ahead of 2015