The Pipo Moteurs RallyX engine is an impressively power-dense machine, making 300 bhp per litre

Specific power

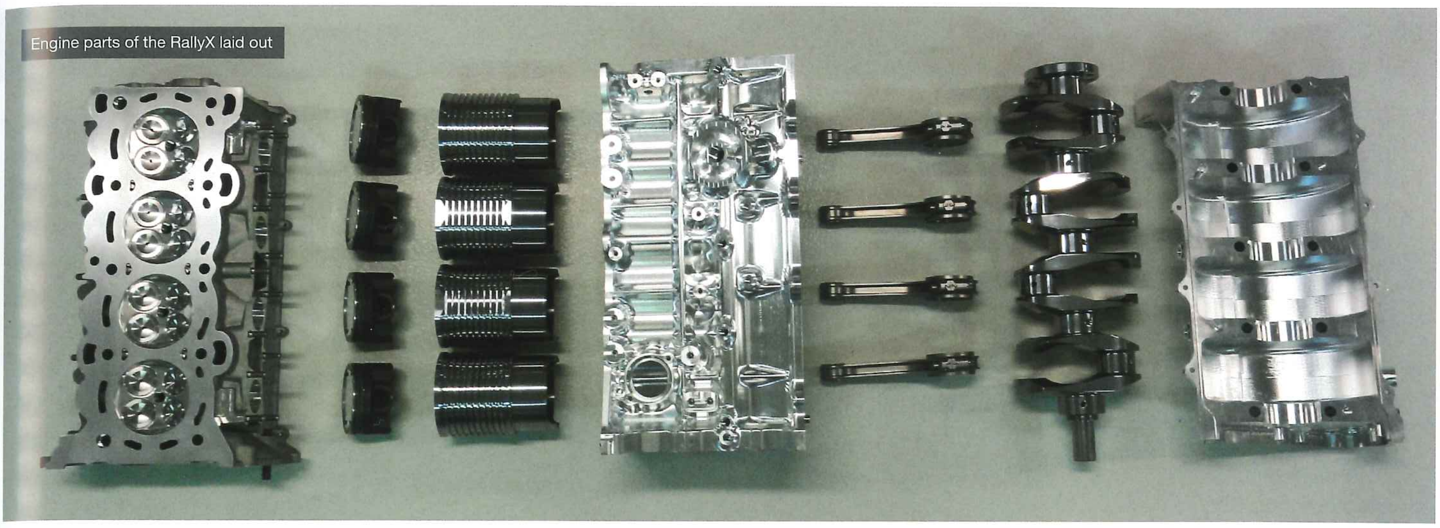
Stewart Mitchell investigates this bespoke engine developed for the World Rallycross Championship

Rallycross, a form of sprint racing held on short circuits that combine tarmac and gravel, has enjoyed a boom in popularity over the past decade. Following its hugely successful introduction in 2010 into US-based annual extreme sports event the X Games, the sport's organiser IMG launched a US national series, the Global Rallycross Championship (GRC).

This fast-growing interest in rallycross prompted the FIA to set up a (truly) global series, so in 2014 it launched the World Rallycross Championship (World RX). There are now 12 rounds per season in this and the GRC, and each attracts factory entries from OEMs including Peugeot, Ford, Audi and Volkswagen.

Rallycross cars are production-derived four-wheel-drive vehicles homologated for Group A and Group N racing classes, meaning they have to be produced in quantities of more than 2500 units in 12 consecutive months, and are powered by highly turbocharged engines. Up to the end of 2015, the GRC and World RX had common technical regulations – both mandated the use of production cylinder blocks and heads, but there were no rules governing the number of engines and components that could be replaced or rebuilt throughout the season.

However, the FIA, which governs only the World RX, found that teams with sufficient resources were changing their engines as much as they wanted, which it felt gave them an unfair advantage. So, with the intention of reducing the potential performance differential between teams with differing budgets, it introduced a series of new


Engine parts of the RallyX laid out

technical regulations for the 2016 running of the championship.

It ruled that each car would be allowed only three engines per year of competition. The engine platform would remain as in previous seasons – a 2.0 litre turbocharged I4 fitted with a 45 mm restrictor – but the engine suppliers would be able to build bespoke engines without having to rely on any production parts. There are a few restrictions concerning weights and dimensions of internal parts, and the use of exotic materials, but little else concerning engine design. The FIA now also allows engines to be mounted longitudinally or transversely in the engine bay, with an incline of up to 35° from the normal vertical plane.

Soon after the FIA published the new regulations, engine developer Pipo Moteurs, based in Valence, France, took the opportunity to produce a bespoke engine. The company's engine development manager Fred Barozier says, "We were very excited that the new regulations allowed us to develop our own engine platform without having to keep within the constraints of an OEM engine, as we'd had to before. We laid out some objectives for the engine, quickly decided on some of the geometries and moved on to the construction from there.

"Our target was to build an engine that would last the whole season, as we were confident that we could produce something that would be competitive, yet would last. That would secure more customers and give them more budget and time for developing the car to perform on the circuit rather than maintaining mechanical parts and so on."

Pipo Moteurs planned to compete in the 2017 championship against several other highly experienced engine developers. Its rivals included fellow French engine developer Oreca, which produces engines for Peugeot's factory entry; Volkswagen, which builds its own engines in-house for its factory efforts in the World RX and GRC, and Audi's undisclosed independent engine builder.

Work on the engine began in early 2016, and the company soon secured customers in the form of MJP Racing Team Austria and its two Ford Fiesta ST supercars, developed by MJP and driven by Timo Scheider and Kevin Eriksson. Barozier notes, "We had developed the production-based engines for the team in previous years, and they were very happy to use the new engine when it was ready."

Engine overview

The engine is a turbocharged 1997 cc I4 with a bore and stroke combination of 85 x 88 mm. Of the design concept, Barozier explains, "We implemented a lot of the knowledge amassed over the 20-plus years of working in the WRC. We have used many different bore and stroke configurations in I4 engines over the years, from ones with a bore of 84 mm up to 88 mm and strokes between 82 and 90 mm. We found that a 2.0 litre I4 with a maximum engine speed of 8500 rpm, an 85 mm bore and an 88 mm stroke, gave us an excellent compromise between torque and maximum engine power potential.

"Of course, with a larger [than 85 mm] diameter bore, larger valves can be used and so a higher volumetric efficiency can be achieved. However, with a big piston there is more heat transfer from the combustion gases to the piston and the cylinder head – increasing the cooling requirement of the engine and reducing knock resistance.

"As this engine is heavily turbocharged, maximum boost pressure is 4.5 bar absolute, so we aren't concerned about volumetric efficiency that much, but we found that 85 mm also provides us with a good compromise between the filling of the chamber at 8500 rpm and the temperature induced by the combustion gases."

When Pipo Moteurs began designing the engine, the plan was to exploit the maximum incline limit of 35°. The engine would be designed to mount transversely, and would incline rearwards to shift its centre of gravity rearwards as well as lower it slightly.

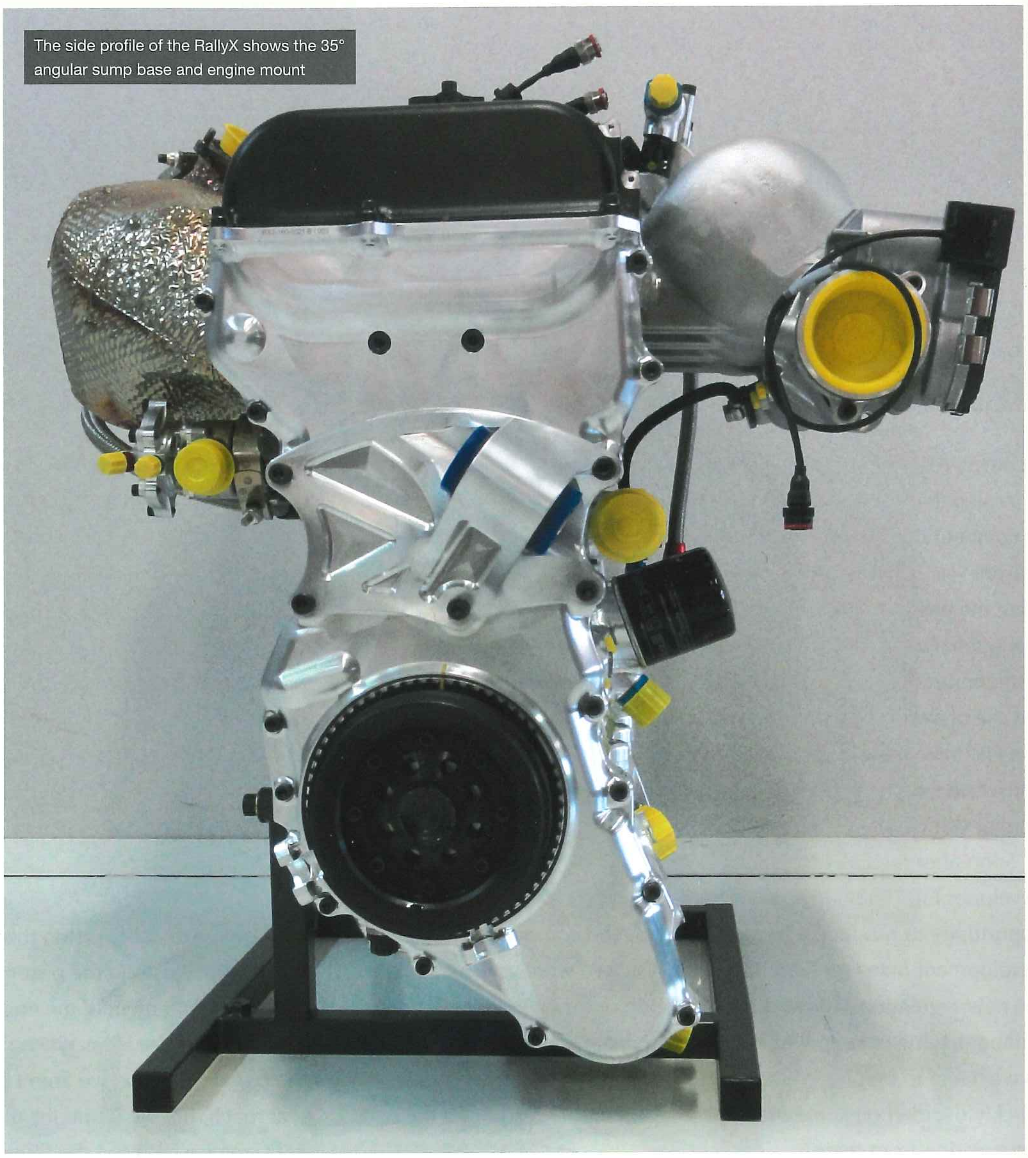
This target was considered throughout the design process, and particularly affected the fluid systems in the engine. Barozier notes, "We needed to make sure we could bleed the full water system from the cylinder head and block evenly throughout the engine. We also had to ensure that all the oil from the turbo and the cylinder head could drain efficiently.

"When you consider these parameters at the beginning of a bespoke engine project, it is not much of an issue. However, when we used to start with the production engines and tried to lay the engine at an angle, it caused massive issues for the oiling system and was very challenging to integrate with the gearbox. We wanted to ensure this was never going to be a problem with this engine, so we kept that in mind throughout the engine's development."

ANATOMY

PIPO MOTEURS I4 TURBO RALLYX

I4
85 x 88 mm = 1997 cc
Turbocharged
102 RON gasoline (FIA World RX spec)
Aluminium block and head
Nickel silicon carbide-coated steel liners
Five main bearings, plain
Steel crankshaft, 5 pins
Steel con rods
Aluminium piston, three rings
DOHC
Four valves per cylinders, one plug
39° included valve angle
32.5 mm (1.34 in) intake valve, 28 mm (1.14 in) exhaust
Electronic ignition
Port injection
Engine management system
10.5:1 compression ratio
Maximum rpm, 8500



The side profile of the RallyX shows the 35° angular sump base and engine mount

The Pipo Moteurs I4 Turbo has an all-aluminium structure. Head-to-block sealing is by means of a bespoke six-layer stainless steel gasket. The head is a bespoke casting with machined combustion chambers and camshaft caps.

The valves are sodium cooled and chrome plated, and use a standard spring retainer system, with twin interference-fit steel springs. The DLC-coated double overhead steel camshafts have five journals running directly in the head, secured by five caps. They directly operate domed steel tappets.

The pistons are a three-ring aluminium alloy production. The crown is a flat-top design with shallow valve cut-outs. The steel piston pin is through-drilled and is retained by round wire circlips, which run in semicircular grooves.

The con rod is an H-beam design with a two-bolt cap, using a straight split and ARP 625 custom age bolts screwing directly into the main body of the rod. It is produced in aerospace-grade steel material and drives a bespoke billet steel crankshaft.

Driven from the front of the crankshaft, the timing chain has a hydraulic tensioner with a mechanical stop.

The front engine cover is a bespoke item incorporating the 35° rearward-angled floor of the engine. Ahead of the timing drive on the crankshaft is a flange to which the torsional damper is fitted, which in turn drives the alternator belt.

The alternator is bolted to the inlet side of the engine block and is belt-driven from the crankshaft.

The integrated sump and lower crankcase part connects to the integrated upper crankcase and cylinder block by an outer ring of ten steel bolts.

The electric water pump is fixed to the body shell. The cooling water flows in a specific pattern to cool down the engine using a flow rate of only 160 litres/minute.

The oil pump (internally chain-driven) is incorporated into this lower section at a 35° incline to make a flat surface when the engine is transversally mounted at 35° towards the rear. The pump is mounted to the side of the sump; the oil pressure is in the region of 5 bar.

The pressure stage feeds oil into the main gallery, from which there is a feed to the piston-cooling squirt jets (two per piston) and a feed to the turbocharger. There is also a feed to the head from a central gallery.

Within the head there is also an oil gallery on each side to feed the camshaft journals. The oil fed to the cylinder head and turbocharger drain back to the sump via galleries running through the block that have been designed to work with the 35° incline of the engine.

For the engine intake at the front of the car, the incoming air is ducted through a filter and then passes through the mandatory 45 mm diameter restrictor mounted 50 mm ahead of the turbocharger compressor. The compressed air is fed via a nose-mounted aftercooler into the main plenum.

The cast aluminium inlet manifold with a single electric throttle is integrated with the tapered intake trumpets as a single piece. The eight injectors are fitted in line on the manifold just before the cylinder head flange.

The exhaust manifold is four into one and 3D-printed using Inconel, with wastegate and anti-lag system (ALS) housings. Both the wastegate and ALS housing are developed by Pipo Moteurs.

The Motec engine management system controls the ignition, the injection, the wastegate and the ALS. It provides launch control capabilities as well as recording data from the engine during races.

The ignition system is a coil-on-plug type using production car coils that have an integrated amplifier, and are driven directly from the ECU. The fuel pressure is 10 bar from the Bosch electric pump (6 bar at the nozzle with 4 bar boost pressure).

The engine has a conventional flat-plane four-cylinder crankshaft, and the firing order is 1-3-4-2. The engine is mounted in the tube spaceframe chassis of the World RX cars.

The gearbox is a bespoke part designed by Sadev for the Pipo Moteurs RallyX, and mounts to one end of the engine.

The complete engine assembly weighs 90 kg (excluding fluids, aftercooler, radiator and associated piping) and takes about 70 man-hours to strip and rebuild.

SOME KEY SUPPLIERS
Block: undisclosed
Head: undisclosed
Other castings: Foley
Liner coating: Capricorn
Crankshaft: Scam
Camshaft: Scam
Timing chain: iwis
Tappets: Xceldyne
Pistons: Mahle
Rings: Mahle
Piston pins: Mahle
Circlips: Mahle
Con rods: Scam
Big-end and main bearings: Mahle Clevite
Studs: ARP
Valves: Xceldyne
Valve springs: PSI
Ignition system: Bosch
Spark plugs: NGK
Coils: Bosch
Injectors: Bosch
Engine management: Motec
Sensors: Bosch
Sensors: Qlite
Sensors: McLaren Applied Technologies
Data acquisition: Motec
Throttle: Bosch
Water pump: Pierburg
Oil pump: Dailey Engineering
Oil filter: Purflux
Exhaust: Defi-Concept
Induction: Garrett
Air filter: K&N
Fluid lines: Goodridge
Wiring loom: BMZ System
Fuel pump: Bosch
Fuel: P1
Oil: Motul

From the outset, Pipo Moteurs worked closely with gearbox manufacturer Sadev to develop a gearbox to suit the engine's packaging requirements. Barozier says, "We knew from the start that with a transverse engine and the 35° incline, there would be very little room for the gearbox after the turbocharger, all its pipes and coolers, and other ancillaries, were placed in the car.

"As soon as we finished the first renderings we therefore sent them to Sadev to develop an efficient interface between the engine and the gearbox in the smallest packaging envelope possible. They have come up with an elegant solution that is unique to our powertrain and works extremely well."

From the start, the company's objective was to sell the engine and transmission package to any customer in rallycross. Therefore, throughout the design process, a small overall packaging platform was paramount to ensure that the powertrain could fit into any homologated chassis.

Block

The block and crankcase are made from an aerospace-grade aluminium alloy. The cylinders and the upper crankcase section are machined from a single billet, as are the lower crankcase, and integrated sump and oil pump housing. Pipo Moteurs declines to name the exact alloy used but says it is similar to but better than 7075 aluminium.

Barozier specified to the alloy's supplier that the billet should not only have high strength but also that its material properties should be consistent throughout the entire piece. The billet goes through a series of post-production heat treatments to relieve stresses caused during manufacturing, to produce the desired material characteristics before it can be machined into the engine block. The block and crankcase start life as a 100 kg cube that is cut down to a 15 kg part for the final product, including the lower crankcase and integrated sump section.

The geometry of the block was specified such that it could be used as a 2.0 litre engine for rallycross as well as a 1.6 litre unit for the WRC, WTCC or any other global race engine championship, if so desired by a customer. To that end, the cylinder spacing was critical to ensuring that the engine would qualify for competition in any of those series, or could be optimised for specific race series.

For WRC, the bore spacing is set at a minimum of 94 mm from centre to centre. With an 85 mm bore, this spacing offers a 3 mm wall around each cylinder. The engine has a bore spacing of 96 mm to provide some extra protection and durability, as well as to keep a clear path for cooling fluid in the cylinder liners.

Barozier says, "To keep decent cooling efficiency around the liner, the bore spacing must be wide so that it doesn't restrict the flow of water around the engine, as that can lead to hotspots in the block and eventually weaken areas of the engine."

Each cylinder is fitted with a steel wet liner with special seals in the cylinder head and around each liner to prevent any issues with coefficients of expansion between the liner and the aluminium block. Cooling water feeds from the radiator to the bottom of the liner channels, and flows from there up to the cylinder head. The channels in the liner core have been designed for this flow action, and have specific features and diameter changes to ensure that the most efficient flow rate and heat transfer versus pumping losses are achieved.

The water is driven around the engine by an electric water pump that flows the water from the cylinder head through the radiator before the circuit begins once again at the base of the liners. Barozier notes that the pump afforded the engine higher cooling efficiency as it does not depend on the mechanical drives that in turn rely on engine speed.

He says, "As the rallycross engine is restricted, it has a flat power curve. For that reason, constant flow and cooling are required because the heat exchange characteristics are very similar throughout the rpm range. For an engine that produces different power characteristics at different engine speeds, a pump that matches the engine speed and therefore the cooling characteristics would be required. For us though, with constant power, constant water flow is necessary for high efficiency." ▶

The RallyX has custom-designed flat top pistons

edge step on the upper ceiling of the intake ports to help accelerate the air-fuel mix into the chamber and reduce the amount of mass flow hitting the valve.

Barozier says, "Since 2010 we have been producing sophisticated direct injection cylinder heads for the WRC. Over the years we have made some major improvements to the design of the intake ports concerning the tumble of the fluid as well as the bulk motion of air as it enters the chamber.

"The features we have implemented for the direct injection WRC cylinder heads are in fact beneficial to all cylinder heads, as the goal is always to improve the filling of each cylinder over a given crank angle period. The fluid is also in a better condition for combustion at the ignition time. That leads to a more controlled burn with better energy distribution throughout the combustion chamber, which leads to more power per volume of fluid introduced to the chamber."

The cast cylinder head design was completed using CAD software. Then, using rapid prototyping, Pipo Moteurs made a single-cylinder model of the design and validated it on a flow bench to test the solution in 'real-world' conditions. The idea was then further refined and validated using computer-aided simulation.

The valvetrain is a very conventional four-valves-per-cylinder layout, with a direct-acting DOHC arrangement. The intake valve angle is 20° to the vertical, and the exhaust sits at 19°.

Pipo Moteurs designed the cylinder head with these valve angles to

Having an electric water pump also means the pump can be operated when the engine is not running, therefore cooling the engine after the race using battery power. As such, the contraction rate of all the components in the engine can be carefully controlled.

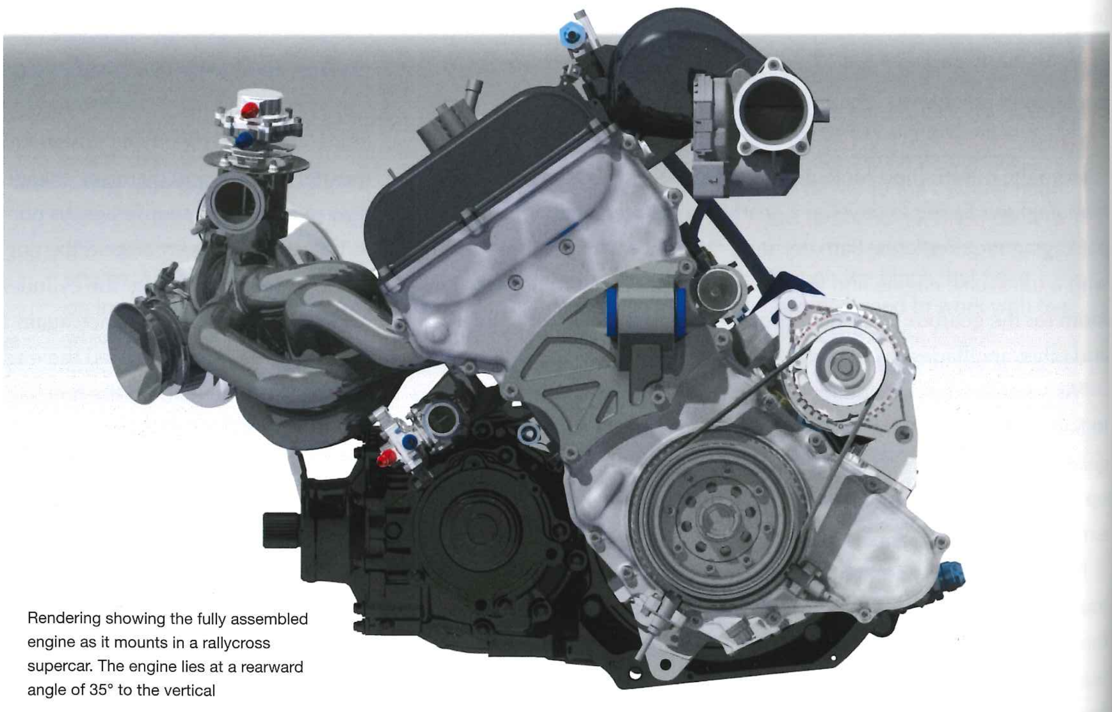
The chosen pump draws around 30 A from the electrical system. As rallycross races are short, around 5 minutes, the power consumption is not a huge consideration for this part.

Cylinder head

The RallyX is port injected, as Pipo Moteurs felt this offers the best engine control set-up for rallycross.

As Barozier explains, "Both DI and port injection systems have their own limits, depending on the engine context. DI has usually one injector per cylinder whereas we can have two injectors on the port injection system. Due to the high power density of our engine and the engine speed, we need a huge fuel flow at full load. With high flow injectors the injection time will be very short at low load or on ALS mode. With two injectors per cylinder we can use one low flow injector when low flow is requested by the engine and the two injectors when the maximum flow is requested. It therefore made more sense to use two port injectors per cylinder rather than one DI injector on the rallycross engine, to have a consistent fuel mixture on all loads."

The intake port profiles combine features from port injection and direct injection engines. They have a smooth shape to help high flow to the back of the valve, and a sharp



Rendering showing the fully assembled engine as it mounts in a rallycross supercar. The engine lies at a rearward angle of 35° to the vertical

The cylinder head is cast, with oval inlet ports

keep the combustion chamber ceiling area small, thereby minimising the heat transfer from the combustion gases to the cylinder head. Barozier says, "We found the solution we have used to be the best compromise between our heat rejection target while also leaving enough room for the spark plug and cooling channels around it in the cylinder head."

The inlet valve head measures 32.5 mm, the exhaust 28 mm; valve lift is set at the maximum permitted 12 mm. The camshafts are DLC coated and directly operate the valves via tappets over valve springs. The tappets feature a domed profile to their top.

Barozier says, "The advantage of the domed tappet is that we can have more cam acceleration with a smaller tappet diameter and as such can reduce the tappet weight. For example, we can have the same cam acceleration with a 31 mm domed tappet as that of a 36 mm flat tappet. We have been working with domed tappet profiles for many years now, and developed one uniquely for this engine. It combines the simplicity and low cost of a conventional tappet over a spring valvetrain design with some of the dynamic opening and closing profile as achieved in a finger follower valvetrain. It is a very elegant solution that we believe to be the best compromise between the two valvetrain types."

The domed tappets weigh 18 g each and sit on double straight valve springs that have what Barozier describes as a "small" interference. During testing of the engine, Pipo Moteurs experimented with lower valve spring pressures using single springs. However, because of the immense pressure inside the intake manifold and exhaust system from this heavily turbocharged engine, high tension on the valve is required to keep the valves closed on the strokes where the pressure is highest in the manifolds. High tension is also necessary to ensure that the valve lifting follows the camshaft profile.

Internals

The crankshaft is machined from billet steel and nitrided for extra strength. The regulations state that it must be steel and manufactured as one part and weigh a minimum of 13 kg. The RallyX crankshaft weighs 15 kg, and there are a couple of reasons for that, according to Barozier.

The first reason is balancing. The crankshaft has large counterweights to smooth out some of the combustion vibrations and lower the peak stress it experiences. The crankshaft counterweight design is conventional, and has a relatively even spread of weight across its length.

The second reason is to help increase engine inertia for the launch at the start of a race. As rallycross races are so short, there is little time to compensate for a poor start, so the launch is more critical than in many other forms of motorsport, and is akin to drag racing. The higher inertia makes a start easier for a driver, meaning they can launch more consistently and with a greater margin of error.

Inherent in using a long-stroke engine is high crankshaft torsional loads. Pipo Moteurs therefore spent a lot of time optimising the crankshaft's stiffness and damping characteristics. The damping solution was based on the concept for an engine the company developed for the WRC, which was introduced at the beginning of the direct injection era in 2010 as a consequence of the peak stress caused by each combustion event being higher than in the previous generation of port injection engines. The manufacturing process and rubber material are specific to the rallycross engine to support the extra load compared to the WRC engine.

Above 7500 rpm the crankshaft begins to suffer high torsional vibration amplitudes. To counter those it therefore has a motorsport-spec external damper system, which consists of an inertia ring

The camshafts have aggressive cam lobes for high engine speed. They are DLC coated to reduce friction between the lobe and tappet interface

mounted to an integrated flange on the pulley drive end of the crankshaft.

This ring is a conventional design, made from steel, and is fitted with a rubber material inside, the weight distribution of which acts as a counter-force to the inertia generated by the combustion. The effect of the counter inertia is manipulated by replacing the damper rubber material with one of a different density.

Barozier says, "We can reduce the maximum and natural torsional vibration amplitude by 50% using this technique, and the damper is a simple way to tune the harmonics out of the engine at specific revs." As a positive side-effect of introducing the damping ring, the shock loads on the valvetrain are also reduced, adding to the engine's durability and reliability.

The crankshaft is a five plain-bearing design, the main bearing housings being machined into the crankcase sections. The regulations stipulate plain bearings with a minimum width of 20 mm, which Pipo Moteurs has exploited – the main bearings are 55 mm in diameter, and the con rod bearings measure 46 mm.

"Oil is distributed to the crankshaft from each bearing of the block. A lot of effort has also been placed on the bearing design to ensure there is no area on the bearing that could cause the loss of the oil film," says Barozier.

The con rod is made from an aerospace-grade steel which Pipo Moteurs has had made specifically for this engine. The big-end bearing is lubricated from drillings within the crankshaft in the usual manner. The regulations mandate that the weight of each con rod is a minimum of 550 g, and Pipo Moteurs has exploited that by using an H-beam design.

Barozier says, "We chose an H-beam design as it easily managed our requirements regarding weight and strength. However, I believe the 550 g minimum weight is so high that either the I-beam or H-beam design would be able to cope with the loads."

The pistons are made in Europe by Mahle, and have been designed purely for Pipo Moteurs. They are a straightforward design with no notable features on the crown other than shallow valve cut-outs.

Barozier says, "The piston was another reason why we didn't go for direct injection on this engine for rallycross, as it afforded us a simpler design. With a simple piston, you can dispatch more of the heat across a larger proportion of its surface. With a direct injection piston, the bowl-in-crown design gives a larger surface area, which can induce more heat transfer into the part. That requires more cooling, which produces additional parasitic losses."

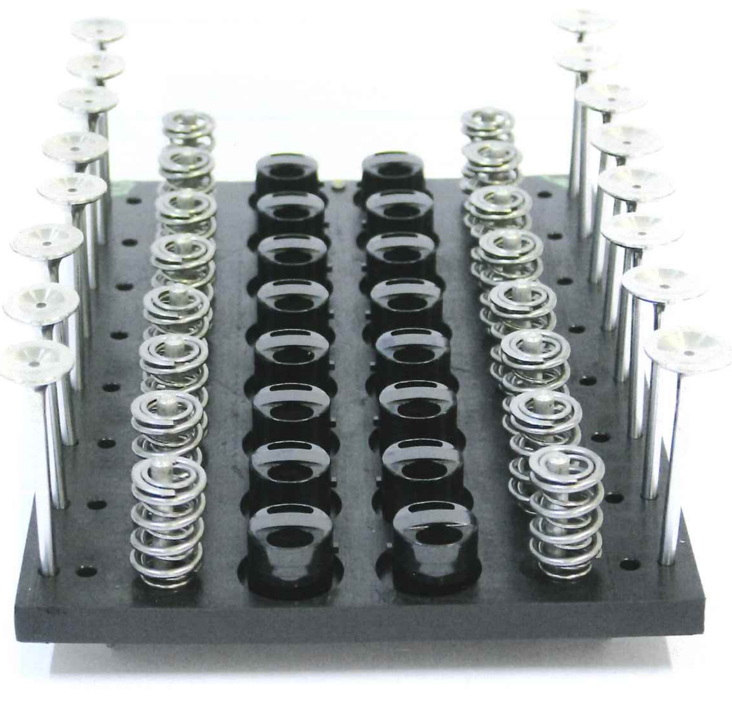
The piston is cooled by a multi-jet system that sprays oil onto the underside of the piston around each side of the pin.

Lubrication

The lubrication system includes four scavenging stages, one for each crankcase compartment, bolted to the sump. The scavenge side operates at a nominal vacuum of 500 mbar.

The pump pressurises the oil to 5 bar and has a flow rate of around 35 litres/minute. All the oil galleries are machined into the respective sections and crankcase during manufacture, and the turbocharger has

The valves, double valve springs and DLC-coated domed tappets before engine assembly



The crankshaft is a steel construction, purposefully over the regulation weight to increase engine inertia and prevent bogging for the critical launch in rallycross races

its own feed.

Barozier says, "We have spent some considerable time developing the lubrication system. Although the service mileage of this rallycross engine is very low, the shock loads on the cranktrain are very high, so it was critical that we designed a system that would maintain a high enough pressure to keep an oil film on the components throughout those severe load cases."

To further support the components under high load, the engine uses high-viscosity 10W40 oil. To put that into perspective, the current WRC engines (which have a similar engine layout) use 0W20 oil viscosity and an oil system pressure as low as 3.5 bar.

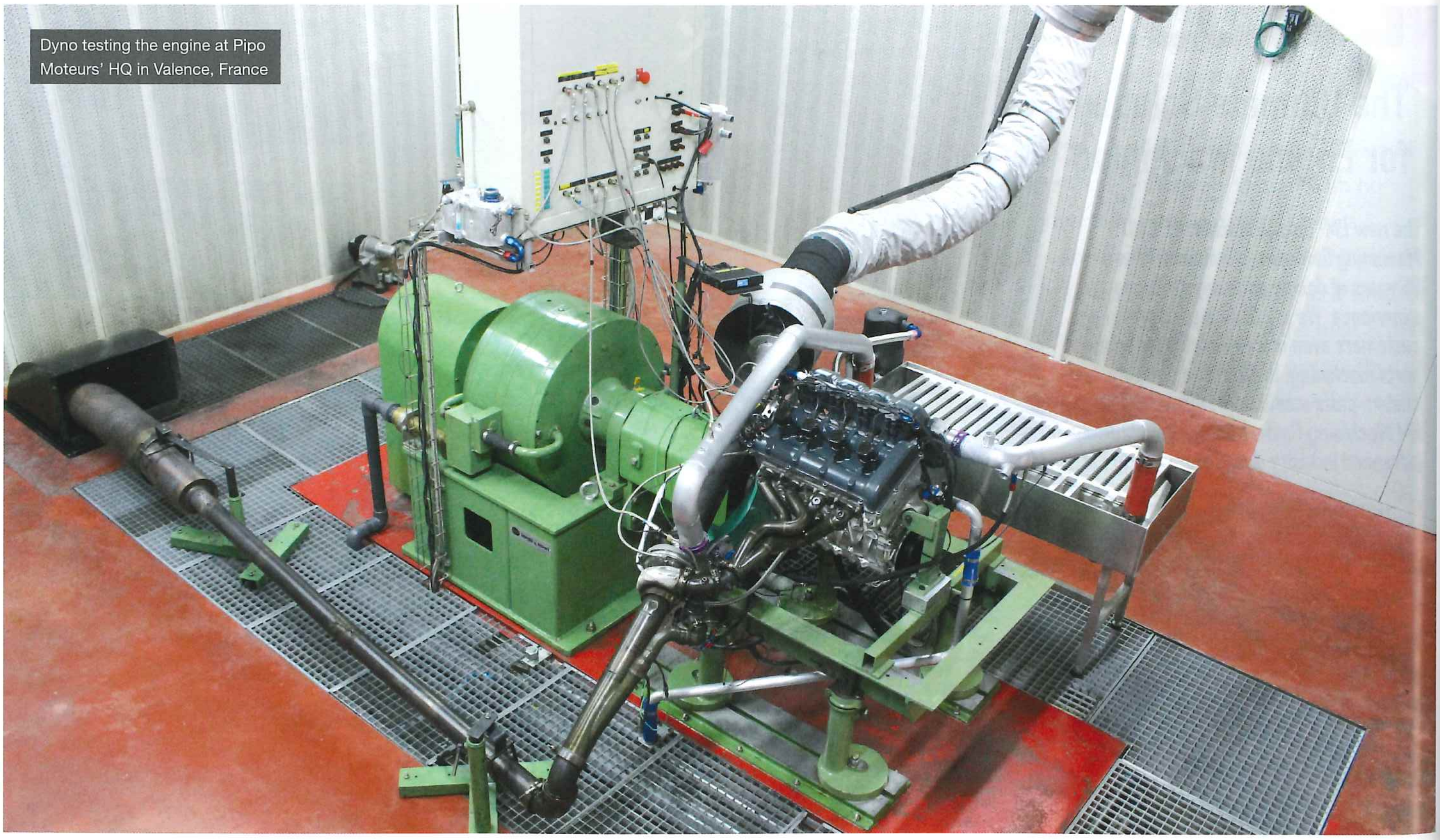
Turbocharger and anti-lag system

The turbocharger has been developed in partnership with Garrett Honeywell, and has been matched for this engine, restrictor, compression ratio and exhaust design.

Barozier says, "We have had several iterations of turbochargers for this engine, and changed areas including compressor wheel shape and diameter. The trend throughout our development process has been to reduce the compressor's weight and size to broaden the rpm range from which it can produce the desired boost.

"The turbo design is a compromise between the boost created at the top end and the driveability. Driveability over the rpm range is crucial in this discipline, because the rpm fluctuates so much as the surface changes and the wheels spin and grip on the semi-slick tyres, and of course the nature of the racing is very on/off the throttle."

The chosen solution is a Garrett TR30R with modified wheels. It is



Dyno testing the engine at Pipo Moteurs' HQ in Valence, France

Garrett turbocharger fitted with coned inlet and mandatory 45 mm restrictor

mounted high in the engine bay and sits alongside the cylinder head, over the gearbox. The primary reason for that is packaging.

Barozier says, "It is usually a disadvantage to have the turbocharger mounted so high in the engine bay; however, tight packaging of our engine is essential because we want it to be able to fit inside any chassis used for the World RX. Also, as the engine leans back 35° to the vertical, it means that having the turbocharger mounted alongside the cylinder head has less of a disadvantage than it would in a conventionally laid-out engine."

A benefit of having the turbocharger next to the cylinder head is that the exhaust system length is short to the turbine, which in theory means that faster and more energy-dense exhaust gases are reaching the turbine.

The exhaust system is a tightly packaged four-into-one design with equal-length pipes returning from the manifold to a single collector, which is additive layer manufactured from Inconel. Using this method meant the collector's desired geometry could be produced in a much smaller packaging envelope than would have be possible using conventional tube welding.

Also, as the exhaust does not experience much creep stress caused by prolonged exposure to vibrations and high temperatures, Barozier says, it gave the best compromise between temperature capability, flow to the turbocharger and the packaging requirement.

The engine is fitted with an anti-lag system (ALS), an engine air bypass coupled with ECU-controlled engine management. The ALS takes air from the compressor side of the turbocharger to the main plenum, bypassing the single throttle.

The bypass is mapped to operate alongside an ignition delay to initiate combustion of the air-fuel mixture on the exhaust stroke, thereby sending hot, high-pressure combustion gases directly through the exhaust and on to the turbine. That keeps the turbo at an optimum boost-generating speed for when the driver gets back on the throttle.

Barozier says, "We have spent a lot of time developing this system to give the engine the best possible driveability. The challenge here is not just achieving the optimum turbocharger speed for when the driver comes back on the throttle, but also mapping the engine to generate predictable engine braking when the ALS is active.

"There must therefore be a good compromise between what is passed through the ALS and wastegate system on the turbo to make sure that the turbo function – including speed, boost and flow efficiency – is optimal, and have a car that reacts predictably on and off the throttle. Without that, there can be pumping on the turbocharger or surging. If the turbocharger falls into a surge condition, then when the driver gets back onto the throttle there is poor engine response."

Fuel system

The fuel for FIA World RX is a spec blend for the series, and is supplied by the governing body to competitors at each round. It has an octane rating of 103 RON, and Barozier notes that although the fuel is a refined race blend, the teams run the engine right to the limit of knock, and often go into the knock region.

He says, "Maximum torque is essential because the races are so short that teams have to run right up to the fuel's knock limit. Of course, there are some risks with this strategy, but we have taken all of them into consideration throughout the engine's design process and the mapping. Pushing the limit is what is required to win in this sport."

Pipo Moteurs carried out extensive testing of the fuel injection strategy for the engine. It determined that a single large injector would not be capable of controlling the complex fuel requirements throughout the wide rpm range seen in rallycross.

Therefore, two injectors per cylinder flow fuel into the engine and are mapped independently to optimise the fuel delivery. One nozzle is assigned to manage fuel flow requirements when the engine is on anti-lag and for low-rpm response, while the other is mapped to fuel the high-volume requirements at high rpm.

Each pair of injectors is positioned in parallel, and mounted in the top side of the intake trumpet of their respective cylinder, to keep the intake system as short as possible. The intake trumpets are oval in the horizontal plane to accommodate the injectors. This shape aids mixing of the fuel and air passing through the trumpet such that it arrives at the back of the valve as a homogeneous mixture.

The intake trumpets are tapered from the plenum to the ports, but the oval shape remains throughout the length. Each meets up with an oval-profile intake port in the cylinder head. This set-up directs the fuel flow from each injector to an individual valve.

Barozier believes this design is much better for fuel control than feeding fuel from a central nozzle and trying to split the feed around the septum between the two intake ports. The injectors are production car parts but are high-performance, high-durability components.

The fuel pump is an electric motorsport part that produces 10 bar nominal pressure to the injectors. The relative pressure of the intake system at the injector tip at full power is between 5 and 6 bar, as maximum boost pressure within the manifold is 4.5 bar absolute. To maintain the correct fuel pressure differential between the fuel, the injector nozzle and the air in the trumpet, there is a 4 bar regulator controlling the pressure in the injector rail with a drain-back system to match the differential requirements. ▶

COMPANY HISTORY

Pipo Moteurs was founded in 1973 by Jean Pierre Fleur. It started out by tuning performance production-based engines from the likes of Cosworth, Hart and BMW.

Shortly after its inception, Fleur decided to start developing engines for motorsport, and before long the company had won its first race in the European Formula Two Championship in 1975, with a BMW 2.0 litre I4. Over the next few decades, it had several more motorsport successes with large French and European racing teams such as AGS, BP Racing, CiBiEmme, Oreca, Prodrive and Schnitzer.

In the mid-1990s Pipo Moteurs formed a partnership with Peugeot that saw it enlisted to develop engines for the marque's factory effort in the French Rally Championship. Peugeot won the championship in 1995 and '97 with the Peugeot 306 Maxi, and also won the German Touring Car Championship in 1997 with a 406, again powered by Pipo Moteurs.

In 1998, Peugeot announced that it would join the World Rally Championship (WRC) and in doing so it enlisted Pipo Moteurs to design and produce an engine to equip the newly released 206 WRC. In Peugeot's first complete participation in the championship, in 2000, it won the Manufacturers' and Drivers' titles.

2001 and 2002 saw the company secure two more Manufacturers' titles to make it a hat-trick in as many years of competition, and each time powered by a Pipo Moteurs engine.

Peugeot withdrew from the WRC in 2005, ending its programme with Pipo Moteurs. However, Pipo Moteurs' WRC story wasn't over, as during that season M-Sport had asked if it would develop an engine for the 2006 Ford Focus WRC. Pipo Moteurs accepted, and much like the story with Peugeot, its relationship with Ford was a great success, resulting in championship wins in 2006 and '07.

The Pipo Moteurs-Ford relationship continued with the Ford Fiesta WRC Super 2000, and the Ford Fiesta 1.6 direct injection engine, until 2012. At the end of the 2012 season, M-Sport announced it was planning to develop its WRC engines in-house, at which point Pipo Moteurs signed a WRC engine supply deal with Hyundai, which was about to enter the championship.

Pipo Moteurs has also developed an engine for the latest Ford Focus rallycross cars that compete in the GRC in the US, operated by Ken Block and the Hoonigan race team. Several M-Sport Fiesta STs that race in the GRC are also powered by Pipo Moteurs engines. The company developed the engine for Petter Solberg's Citroen rallycross car as well, which won the championship in 2014 and 2015.

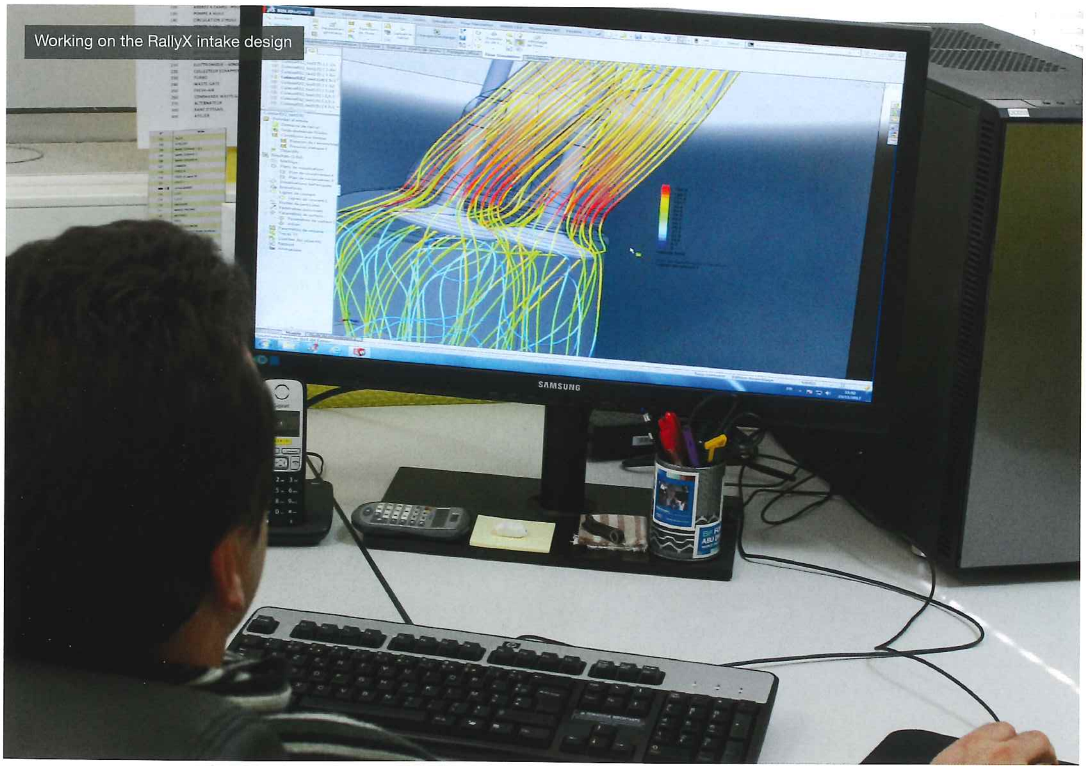
Performance

The engine can run up to 8500 rpm, but because of the choking effect of the mandated restrictor, gear changes usually take place at around 7250 rpm. The restrictor's effect also means the boost pressure generated by the engine drops progressively from a peak pressure of 4.5 bar absolute at the maximum torque speed of around 4500 rpm to around 2.9 bar at 7250 rpm. The engine thus produces its peak torque of 900 Nm (664 lb-ft) at 4500 rpm, and peak power of 600 bhp from 5500 to 7000 rpm with maximum BMEP of 56.7 bar.

The engine made its on-track debut in the third round of the 2017 World RX championship with Team Austria. For 2017, Pipo Moteurs built three race engines for the team: one for each of its Ford Fiesta ST cars and a spare. The engine installation in the Fiestas exploits all the benefits of the FIA regulations, lowering the engines centre of gravity to the minimum permitted 110 mm above the crankshaft axis.

Barozier notes, "To date, the engine has run faultlessly, and we will receive the engines back from the team in mid-December [at the time of writing], at which point we'll strip them, analyse their condition and refresh anything as required before the 2018 season."

At the end of the 12-round season, Scheider and Eriksson had finished ninth and tenth respectively.



Working on the RallyX intake design

For 2018, Pipo Moteurs plans to introduce a new ECU with specific engine strategies developed from its WRC programming. The ECU will be from Motec, and supplied by Pipo Moteurs distributor Stohl Group for the company's European customers.

Pipo Moteurs plans to produce engines for six cars in total for the 2018 World RX Championship. Barozier says, "When we produce engines for six entries, there is the potential to power every car in the final of any round of the championship.

"That is the best chance you have to win – and that's what we plan to do!"