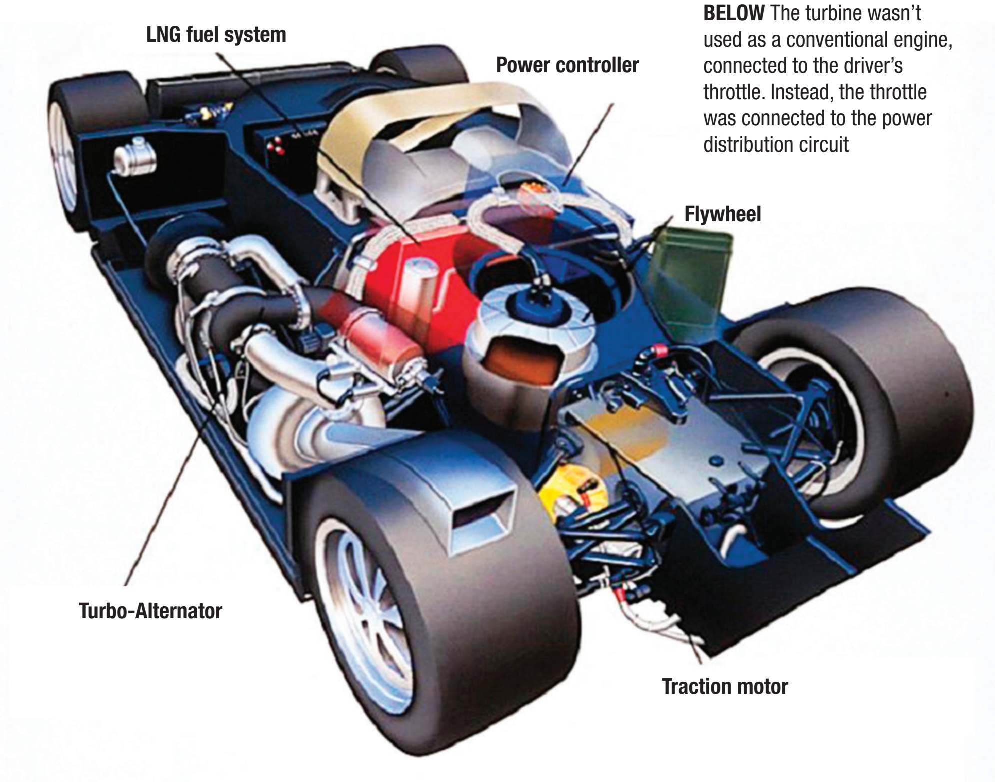
20 YEARS ON, PATRIOT DREAM IS RE-IGNITED

Chrysler's Patriot sports prototype was a hybrid designed to race at Le Mans on Liquid Natural Gas. It was conceived with a turbine, energy recovery system, blown diffuser technology and widespread use of GPS. Here **Ian Sharp**, the car's creator, reveals the secrets that lurk beneath its skin – and a sensational twist in the tale…

LIKE an eccentric child kept hidden away from public view, one of Chrysler's two remaining Patriot Le Mans racecars has spent most of its life sitting forlornly in the basement of the Chrysler Museum in Auburn Hills, Michigan.

The vehicle had a difficult birth and early childhood, being neither loved nor desired by the Chrysler engineers who eventually, much to my chagrin, were told to "can" the design. Why would they love it? It was so different from what they had been brought up on. Their belief of what the future should look like revolved around the super-successful NASCAR model, which many of the US public thought was the pinnacle of automotive technology. I have great respect for NASCAR, which delivers huge entertainment and commercial success, but at the time the Patriot was conceived NASCAR was still 20 years away from racing on fuel injection systems.

As for the "corporate" engineers, who had suffered the hybrid Le Mans project being thrust upon them, such a creature was simply beyond the realm of their imagination. It had not been conceived in an anonymous, white board-festooned committee room by consensus, and therefore they were not vested in the project.

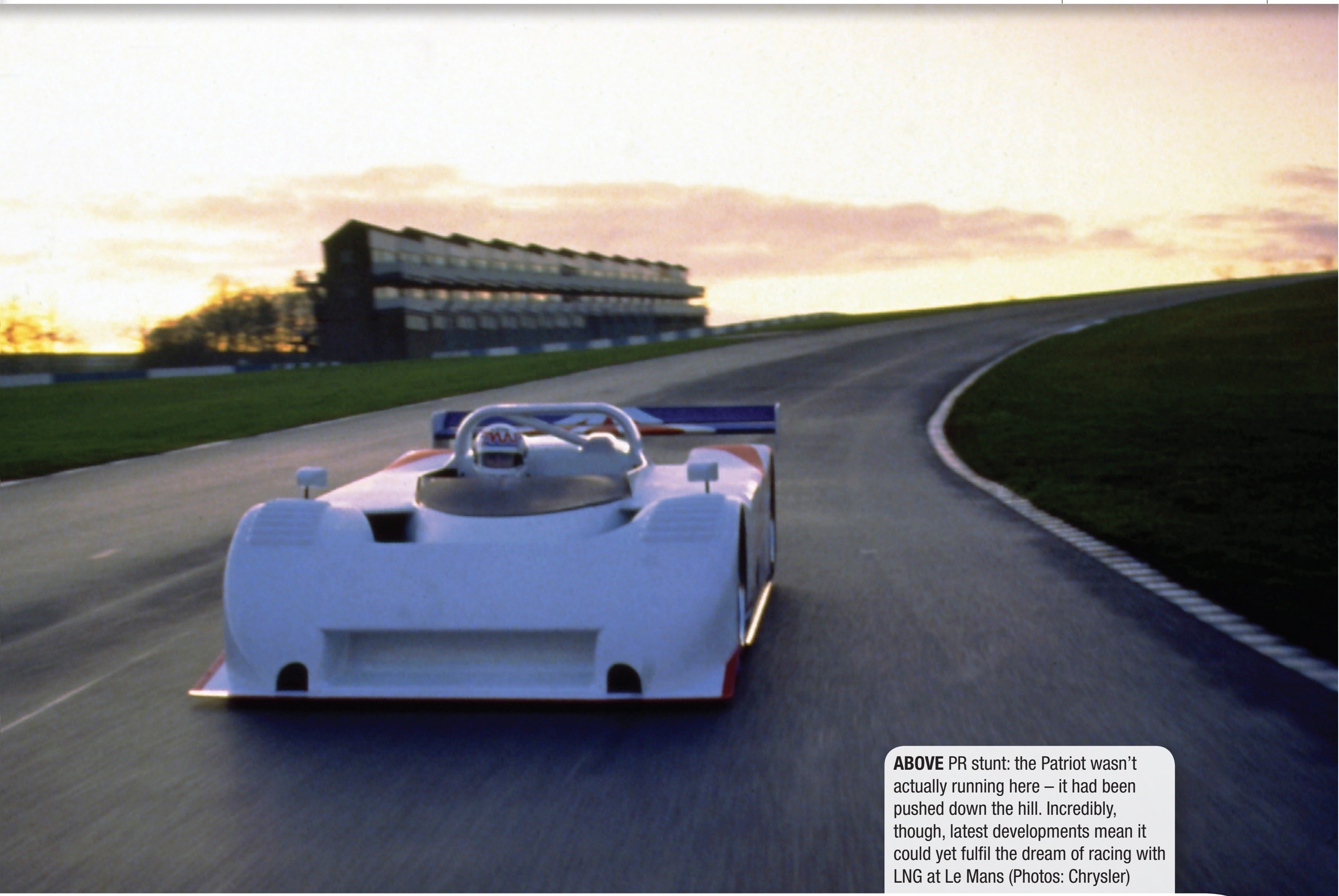


BELOW The turbine wasn't used as a conventional engine, connected to the driver's throttle. Instead, the throttle was connected to the power distribution circuit

In fact, one disgruntled Chrysler engineer spent his own money to print a book trying to debase the concepts therein and other advanced work Chrysler was undertaking. Unfortunately there was, and still is, a Luddite mentality in some areas of the US auto industry.

The Patriot was an unashamed attempt, even 20 years ago, to showcase technologies that would address "dirty" fossil fuel consumption and the venting of noxious gasses into the atmosphere. The genesis of this thinking was the use of LNG (Liquid/Slush Natural Gas) as the fuel source.

My abiding belief is that in 2013, there is still not a viable technology available that can substitute for the process of combustion to release energy from a given fuel. I do believe in the nuclear process, both fission and fusion, but appreciate that mankind has demonstrated an unerring ability to shoot itself in the foot over nuclear technology. So if we accept that for a time we are still going to need to combust a fuel, let's at least burn one that is abundant, cost-effective and cleaner, with the clear objective of learning



ABOVE PR stunt: the Patriot wasn't actually running here – it had been pushed down the hill. Incredibly, though, latest developments mean it could yet fulfil the dream of racing with LNG at Le Mans (Photos: Chrysler)

where to go in the future.

This belief underpinned my vision for the Patriot. So too did the desire to harness energy recovery systems, reusing the energy released in the combustion process in order to go further and faster. The car was specifically designed to be a stepping stone to fuel cells by using cryogenic engineering. Looking back, I had little idea that the vehicle I proposed to Chrysler's senior management in 1991 would have such relevance today.

> *"The car was designed to be a stepping stone to fuel cells by using cryogenic engineering"*

No idea either, that two decades on, the Patriot might still have a chance to prove itself at Le Mans. During the course of researching this article we tracked down the four Patriot chassis that were built, two of which now reside with Michel Pilon in Quebec.

Michel has contacted me to discuss the possibility of building the Patriot powertrain that was originally designed for the car as per my specifications…

TURBINE

The early hybrid systems developed for the road comprised of two powerplants: the generator and an internal combustion engine. But the Patriot had no conventional engine. Instead, it was designed to be powered by a single axial turbine generator unit, as opposed to the radial turbines which are more common these days. This, together with a carbon fibre flywheel energy recovery system in combination with a small battery pack, would effectively serve as an electro-mechanical and electro-chemical storage system for energy density and power density considerations.

The vehicle was conceived to race in a four-wheel drive configuration, using two centrally-located electric drive motors – one front, one rear – with driveshafts to each wheel running through a simple combined speed reduction gear and differential unit. It was always envisaged that it would run initially in an experimental guise, as the Porsche GT3 flywheel energy storage hybrid does, as it would not have conformed to the rules at that time.

Turbine engines have unfinished business in motorsport – they were even proposed at one point for the post-2013 F1 rules. The suggestion also struck a chord with the management at Chrysler because the company had probably been further down the turbine route than anyone else.

The inline axial turbine configuration was given a lot of thought. The electrical generator was directly connected to the turbine's core shaft on the air input side. In other words, the turbine drew air in through the electrical generator, cooling it, and raising the turbine charge inlet air temperature to have a two-fold benefit. One, to cool the internal core of the high-speed generator, and two to impart that heat energy to the charge air entering the turbine, again creating a closed loop of energy use. Additionally, after the power wheel the turbine would have given up its unused heat from combustion to a ceramic recuperator that transferred the energy back into the incoming airstream. Again, in the case of the recuperator, a closed loop energy recovery system.

A turbine has a lot fewer moving parts than a conventional engine – around 20 compared ▶

to the 200 normally used – and needs a lot less maintenance. It is also much lighter for a given power output (a higher power density) and almost vibration-free to aid durability. Basically, it has all the attributes that you want out of an engine.

The only problem is getting the rotational speeds where it produces its power, up at 60-70,000 rpm, matched to sensible speeds at the wheels, so you need lots of gearing in a mechanical sense. Using one electrical motor fitted to the turbine to develop the power, and another to deliver that power to the wheels, obviates a lot of the gear reduction issues. But it obviously is not as efficient as a direct mechanical flywheel recovery and delivery system, as in Flybrid's mechanical solutions.

BELOW The door to much of the technology proposed for the project was opened by the US government's push for the military to share its expertise with the automotive industry. Here President Clinton and vice-president Gore review the results of their initiative

This is an engineering conundrum still to be solved: mechanical reduction gearing weight vs electrical energy conversion efficiencies. Nevertheless, we felt things could be improved by the cryogenic attributes of the fuel.

The Chrysler Turbine Car of the sixties had featured large gear reduction and our first proposal was to go with Williams International, whose founder, Sam Williams, had been a key figure in Chrysler's early experiments in bringing turbines to the consumer automotive market. But the real impetus for our project came from the government's big push for the military to leverage the money invested into it by releasing its technological expertise back to the automotive industry. We switched to Honeywell (formerly Allied Signal), who at one point had five turbines set aside for us, and 11 technicians to work on them free of charge!

Unfortunately, the final choice of turbine was symptomatic of the manner in which the project would unravel once Chrysler's money men began to get involved and flex their muscles. The corporation didn't care about the timelines of racing. They opted to go for a very unique turbine, rather than taking one off the shelf, as I proposed, that had been developed for a military helicopter.

When Formula One's blown diffuser rumpus erupted in 2011, I was watching it unfold with a wry smile on my face. After all, our plan was always to use the considerable airflow from the turbine to 'blow' the Patriot's diffuser for increased downforce – this discussion had taken place in 1992, remember!

Reynard was building the chassis and we had the packaging philosophy worked out: the inlet would have been over the driver's head, taking air through the generator then into the turbine on an angle facing upwards – similar to how the Rolls Royce 300 turbine is mounted in the new Robinson R66 helicopter at a upward-facing angle. The exhaust would have gone directly down beneath the car.

Originally the turbine would have been turned off along the straight and turned on again to produce power out of the corner. We had even discussed the strategy of switching the turbine back on, onto idle, some way before corner entry to ensure that we were blowing the diffuser to create downforce. When we say 'turned off', we mean going to fast idle, around 20% of full power rpm, with no load on the generator. This was the way to provide turbine efficiencies (which are notoriously poor for fuel consumption) when starting up again from zero rpm. This would also have kept the power wheel and flame cans, the hot part of the engine, close to their ideal thermal operating temperature.

The final iteration of the vehicle that Chrysler produced changed the position of the turbine, so the plan never came to fruition. Nevertheless, Paul Brown – who was handling the integration side for Reynard – and I both had a chuckle when people started getting all agitated about blown diffusers in F1. Imagine that at Le Mans…

CRYOGENIC ENGINEERING

The Patriot was all about using the onboard energy available from the fuel as efficiently as possible to enhance every aspect of the vehicle. Cryogenic fuel storage was central to that concept.

In my initial research I investigated NASA's work on the foams insulating the Space Shuttle. They were designed to keep the liquid hydrogen fuel at minus 423 degrees F and the liquid oxygen tank at minus 297 degrees F, not to mention tolerating temperatures of up to 1,200 degrees at launch. These foams opened the possibility of us running LNG or, to be accurate, refined cryogenically-cooled methane, which is much cleaner burning than gasoline yet yields similar energy density. NASA's suppliers were initially reticent, because the foam was so high-tech, but we eventually got clearance. I wouldn't say the issue went as high as the White House, but it went fairly high...

A cryogenic fuel features not only the calorific value of the fuel itself, but also the energy you have imparted to cause it to change into a liquid. So the car wouldn't have been dragging as much weight of fuel around with it every lap.

We based our calculations on a 40-gallon gasoline fuel tank. LNG is only 59% of the weight of the equivalent volume of petrol, weighing in at 26.47 lbs/cu.ft compared to 44.88 lbs/cu.ft. Its calorific value per unit mass is also 21% better than gasoline, at 23,963 British Thermal Units.lb compared to 19,000 Btu.lb.

ABOVE An exploded view of the cryogenic tank location and the use of the polyisocyanurate coating, which derived from the Shuttle programme

ABOVE Cryogenic fuel storage was a crucial part of the design strategy. The foams developed by NASA to insulate the Space Shuttle's fuel tanks would have enabled the running of LNG in a racecar

So dividing the density of gasoline (44.8 lb/cu ft) by that of LNG (26.47 lb/cu ft) gives a ratio of the densities of 1.6955, while the ratio of energy densities is 0.793. Multiplied together, we get a volume ratio of 1.3443. Therefore an equivalent LNG tank to store the same amount of energy as its 40-gallon gasoline counterpart is (40 x 1.3443) 54 gallons. However, LNG is just over half the weight of gasoline by volume, therefore 54 gallons of LNG is approximately 40 lbs lighter than 40 gallons of gasoline.

> *"Use the airflow from the turbine to 'blow' the Patriot's diffuser for increased downforce"*

Whilst it must be noted that an LNG tank would be heavier than a standard gasoline bag tank, it is also clear that as a side benefit, the car would suffer less from changes to weight and ride height under braking and turn-in.

We wanted to route the fuel – stored at minus 258 degrees F – through the electronics power distribution package and possibly traction and turbine generator motors. The idea was, as with Colin Chapman's philosophy, to utilise components for more than one purpose wherever possible. Rather than using a dedicated heat exchanger to change from the liquid to its gaseous phase for feeding the turbine, our intention was to harness the waste heat from the power electronics and electrical motors/generators, cooling them in the process. This would have doubled or even tripled their efficiency.

The LNG was stored in a double-walled trapezoidal tank behind the driver's seat that matched the angle of the turbine and generator unit. Compressed natural gas would have necessitated a cylindrical tank – hardly a space-efficient design – to equalize the hoop stresses in the cylinder wall, under which the gas is kept at a considerable pressure; LNG, however, could be stored at only 8 psi in a traditional racing car tank shape.

People might shudder at the thought of LNG refueling at Le Mans, but we did have a plan. A fixed-arm overhead boom would have dropped down onto the top of the fuel tank. It was doable, as illustrated by the fact that commercial trucks are now filled regularly with LNG in the USA.

The LNG used on the Patriot would have offered the opportunity to further our understanding of both the pitfalls and positives of cryogenic fuel usage in road vehicles. Twenty years on, the high-quality polyisocyanurate insulation foams developed by NASA are now commercially available. We would have used this both within the double-walled tank skin, and as a secondary insulation in the fuel tank cavity in which the cryogenic tank was fitted inside the tub.

MOTORS

I've heard the rather unkind comment that the project was a "wet dream", the suggestion being that the technology would never have been available at the time to make it all happen. But those people are wrong: the technology *was* out there; not in the automotive sector maybe, but certainly in the military and aerospace industries.

The motors were a good example of that. They were very powerful high-tech permanent magnet motors that had been developed for the Sea Wolf attack submarine by Westinghouse Electric Corp, of Baltimore. I'd say the technology was at least 20 years advanced of where we are now in the ▶

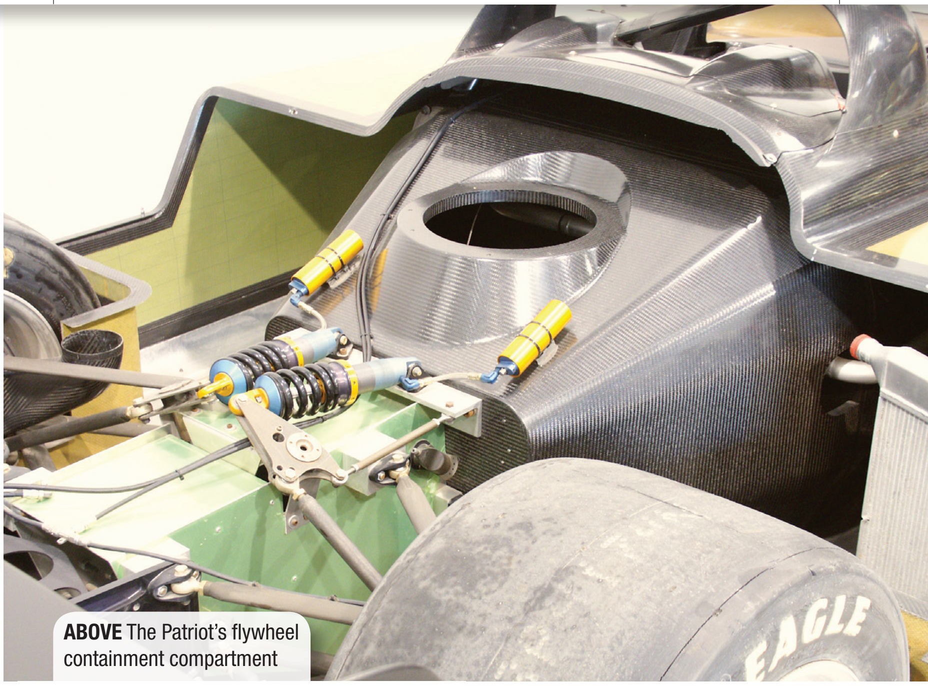
In search of the Holy Grail: no radiators

THE PLAN was not to use any radiators in the Patriot. We had been having these discussions in Formula One for years, how the Holy Grail was the goal of not having a radiator in a racecar, so that was one of the guiding principles we were intent on achieving.

A turbine cools itself internally and the foil air bearing technology intended for the turbine we originally specified further improved the situation. A pressurised bearing would have effectively suspended the turbine core on a cushion of air. This would have brought weight advantages but also crucially meant that no radiators would have been required.

The technology was being developed for a military helicopter and was still in the experimental stage. It hadn't done a million hours of service but it was available for the 40 hours' duration that we needed it for at Le Mans.

We might still have needed a small radiator to cool the power electronics – that depended on how efficient we managed to get the conversion of the LNG to gaseous. Potentially, though, we felt we were on the verge of a huge breakthrough. RT



ABOVE The Patriot's flywheel containment compartment

automotive industry.

They were three-phase, AC, 525 volts, water-cooled, about 18 inches long and 12 inches in diameter. They could run at 25-30,000 rpm – nowhere near the 60-70,000 of the turbine. We were going to detune them to around 15-20,000 rpm so that we didn't have to do so much work on the transmission side.

The electric motors would regenerate power into the flywheel under braking, and also into a small battery pack. Nickel-metal hydride was the coming technology at the time. The Prius used NiMH batteries for most of its life, lithium ion replacing them only in 2012. Our plan was always to discard or upgrade the batteries if possible at a later design stage, as battery technology progressed, or didn't, whatever the case might be.

FLYWHEEL

If there was one area in which scientific progress has advanced beyond all recognition in the last two decades, it is probably the materials technology that has enabled the flywheel KERS to become mainstream. It was interesting watching F1 teams debate the merits of batteries, supercapacitors and flywheels ahead of KERS entering the top flight for 2009, because Chrysler had argued the toss nearly 20 years earlier.

Initial thoughts were of a single flywheel, but this issue increasingly highlighted divisions within the ranks. I thought of the single flywheel as an 'electrical load levelling device', almost certainly supplemented by a battery pack. But the Chrysler guys charged off thinking that the only energy storage they needed was just a large flywheel. There are clearly huge challenges involved with a large flywheel spinning at 58,000 rpm, whereas I envisaged one that was only a third of the size, spinning at 35-40,000 rpm, at which we knew we could control the inertial forces.

As the project unfolded, my proposed solution was to use two contra-rotating carbon fibre flywheels from Unique Mobility. They would have been mechanically inter-connected by a gear, which in turn connected to a centre gear and the electrical motor/generator. Ultimately, Chrysler opted for a unit from SatCon Technology Corp, another high-tech company involved with weapons systems and satellites.

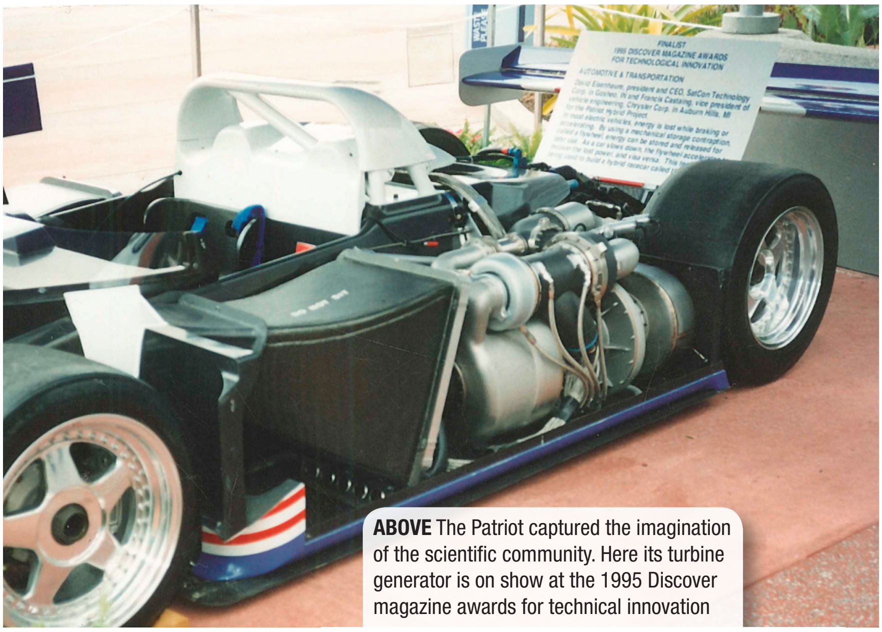
The default setting always available to us was to revert to using batteries. However, specialists were already addressing the operating problems with flywheels. To put things in context, the technology was continually being developed as an integral part of Ronald Reagan's Star Wars missile defence shield, and continues as part of the US Navy Railgun programme.

If ever the subject of the Patriot crops up on an Internet forum, it will inevitably end with the mention of two deaths during testing of the flywheel. I do know by hearsay of the tragic accident that most of this talk refers to, but it involved a European manufacturer. Somehow, it has become something of an urban myth linked to the Patriot. I genuinely am not aware of there having been any deaths on the project. In fact, the flywheel we envisaged using was actually an experimental unit designed for spacesuits, carried on an astronaut's back when walking in space. Its failure mode – which dissipated the flywheel's energy into carbon fibre fluff, without bursting out of its containment – had already been sorted. It wouldn't have been a particularly good PR move using it in a space suit otherwise…

POWER CONTROL ELECTRONICS

In many ways the Patriot's heart was its power management system. The turbine wasn't used as a conventional engine, connected to the driver's throttle. Instead, the throttle was connected to the power distribution circuit. It was always up to the turbine, flywheel energy storage system and the battery to be able to provide the driver with enough power to do whatever he wanted to do, whenever he needed it.

That's the direction people will be going. ▶



ABOVE The Patriot captured the imagination of the scientific community. Here its turbine generator is on show at the 1995 Discover magazine awards for technical innovation

You've got to use the fuel as efficiently as possible and that isn't by allowing the driver to just directly squirt fuel into an engine!

The Patriot was to have used MOSFET (metal-oxide semiconductor field-effect transistor) or later IGBT (insulated-gate bipolar transistor) technology chosen for high efficiency and fast switching. The car would have relied heavily on GPS technology, which is taken for granted nowadays but was still in its infancy back then. The control system would have interacted with the GPS to inform the vehicle of its power state, its position on the track and where energy needed to be routed for the upcoming event.

Approaching a corner, the electrical energy storage system would have been depleted by the acceleration on the straight and might be down to, say, 20 per cent storage. As the car braked it would have filled the flywheel energy storage system and the battery. Coming out of the corner it would

ABOVE One of the remaining Patriots being prepared in Pilon's workshops for a remarkable comeback

have drawn power instantaneously from the flywheel, supplemented by the battery, which takes longer to deliver its power to the traction motor.

The strategy was about being able to spool up the turbine from its semi-torpid state whenever you needed it. The turbine was not directly connected to the motors; it was only there to provide the correct amount of electrical energy in the power supply system, to be drawn upon by the driver for delivery to the traction motor.

A 20% driver reserve was factored in. The turbine could be spooled up or spooled down as power was required, much as a jet airliner spools up the engine when landing, but delivers no thrust, to allow for rapid power/thrust if required in an emergency.

The GPS we proposed – courtesy of the association that Liberty, Chrysler's technical group, had with Northrop Grumman – was a detuned version of the GPS system that was developed for the B1 Stealth bomber. Even in 1992, it was accurate to within less than half a metre of spacial definition, which included elevation above sea level, thus gradient identification.

END OF THE ROAD

The Le Mans 24 Hours was targeted as an excellent way to achieve visibility for the Patriot's technology. It was a 'Box 56' entry, if ever there was, and I have to admit a pang when I see what's gone on with the DeltaWing, the hydrogen fuel cell-powered GreenGT and Pat Patrick's LNG ALMS/Grand-Am vehicles. If only we could do a proper job and bring all these efforts together as the Patriot intended.

The Le Mans organisers, the ACO, should be applauded for their stance on experimental technology and they bent over backward to accommodate us. Francois Castaing, then Chrysler's vice-president of vehicle engineering, had a very good relationship with the ACO. He flew over to meet them and they changed the rules to adopt the Patriot system into them. I remember Jeff Hazell, who was in charge of Spice at the time, saying to me, "What's going on? Somebody must have got something for the ACO to change the rules like this?" I nodded and agreed but I couldn't reveal anything…

Had it raced, the Patriot wouldn't have needed to be the fastest car outright on the circuit; we figured we could capitalise on our inherent fuel economy to make fewer stops than conventional cars. I referred to it as the "Aesop strategy" in the Chrysler Motorsports Committee meeting, because it was a "tortoise and the hare" approach.

We were hoping to lap in the 3m 30s bracket, as opposed to 3m 27s of the opposition at the time, but felt we could have run one-hour stints rather than rivals' 42-45 minutes. This would have given us a 24-stop race, spending significantly less time in the pits than their 33-stop strategy. We believed the powertrain would offer the drivers a quieter, smoother cabin environment – albeit with an open cockpit – and we were in discussions with Goodyear to develop tyres that would have lasted for four-hour stints.

We had such high hopes for the project and the stakes were high. At Liberty we actually looked at how we would package the system in CATIA for a Williams FW14, one of the leading contenders in F1 at the time. We did the same

The time traveller

THE STING in the tail of the Patriot story is that the long-abandoned dream of the project racing as an experimental entry at the Le Mans 24 Hours might still become a reality.

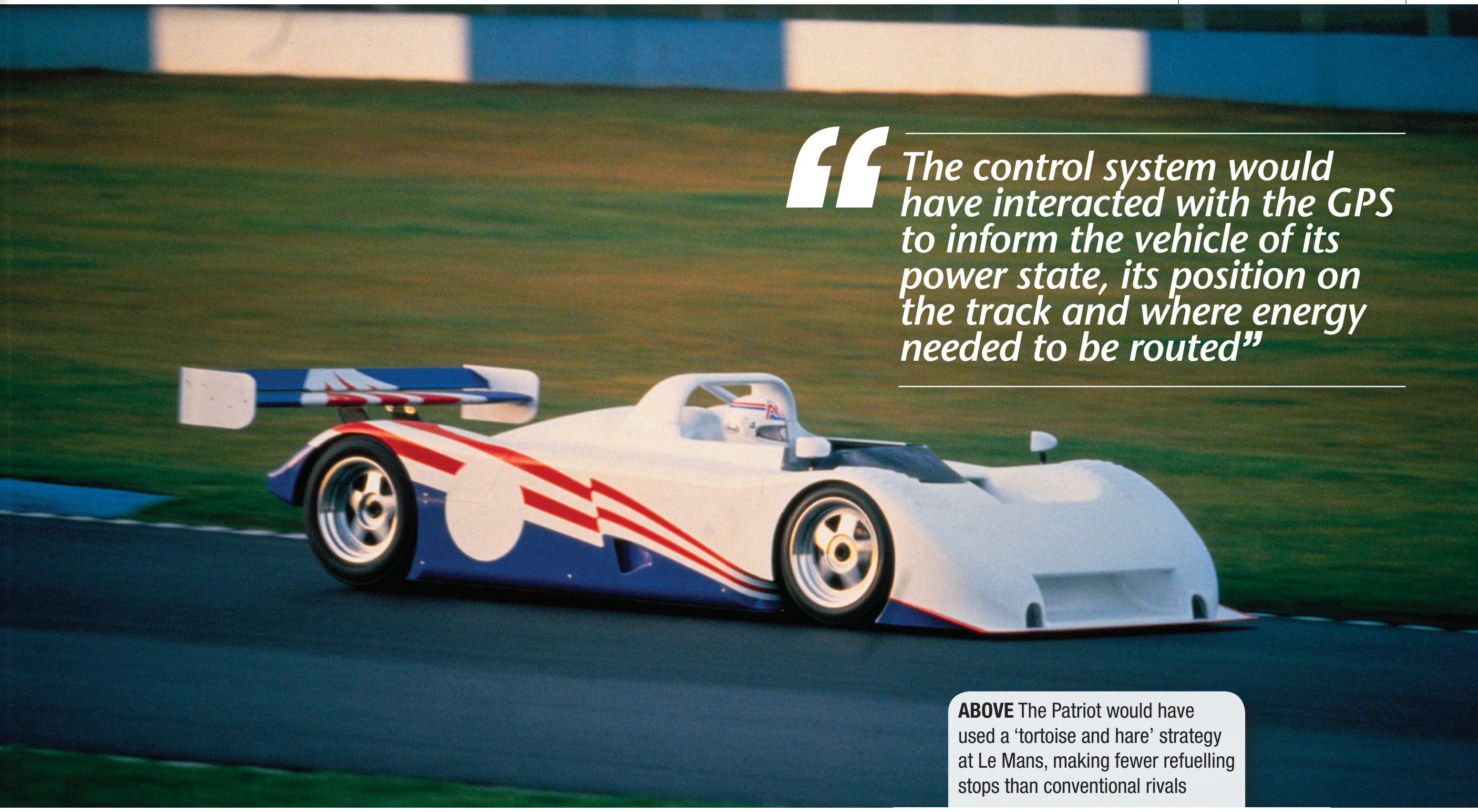
Two of the remaining Patriots have been bought by Michel Pilon, a businessman whose company has a link to the Patriot powertrain through its work with Pratt & Whitney and the Rolls Royce aero engine division.

"I would like to complete Ian's design and have the cars race," says Pilon. "It would be a personal challenge but also demonstrate the possibilities of a design that I feel was 20 years ahead of its time.

"I would like to find partners to develop a complete powertrain to prove the concept and then integrate it in the Patriot bodies. Finally, I'd like to race the cars at selected events to demonstrate the developed technologies."

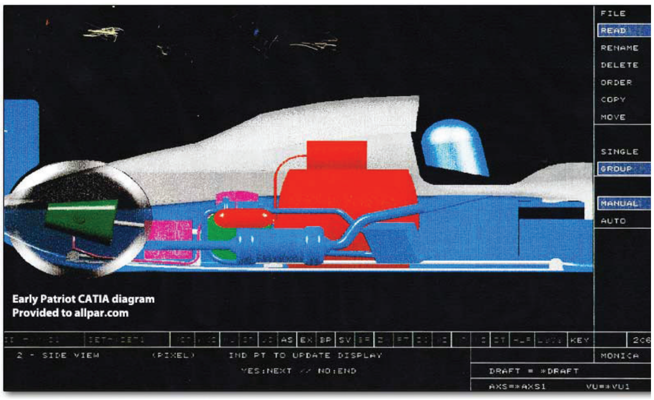
Pilon's company, Aquacoupe, offers a specialised workshop that develops and operates high-pressure water jet cutting and stripping machines and applications. Its 27,000 sq.ft premises are based in Mirabel, Quebec. Its motorsport division prepares Dodge Vipers for different road racing series and also stock cars for the NASCAR Canadian Tire Series.

Pilon originally bought the Patriots to complement the Dodge Viper's racing history. "Not many people know that the racing Vipers, the GTS-Rs, were part of 'Plan B' to go racing when the Patriot project was canned," he reveals. "Since I owned one Viper GTS-R of the P series, one Viper GTS-R of the C series, one Viper Competition Coupe and one Viper ACR-X, the Patriot was the missing link…" RT

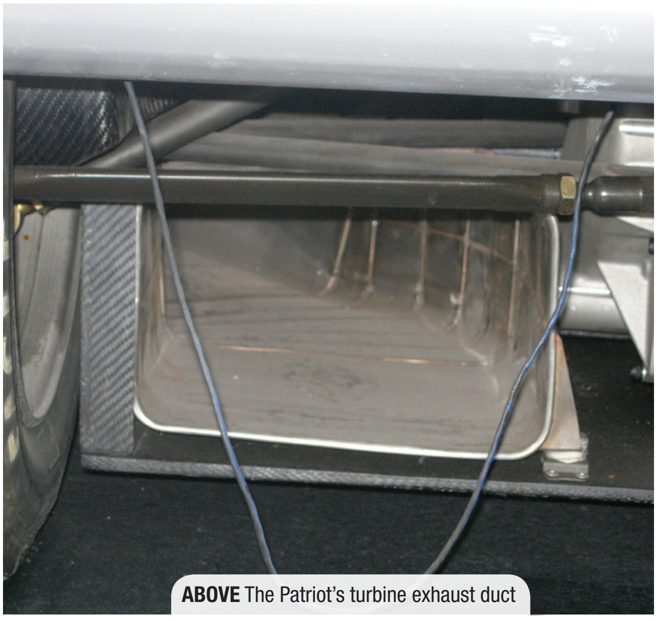


> *"The control system would have interacted with the GPS to inform the vehicle of its power state, its position on the track and where energy needed to be routed"*

ABOVE The Patriot would have used a 'tortoise and hare' strategy at Le Mans, making fewer refuelling stops than conventional rivals



ABOVE Big plans: the hybrid system was even modelled in CATIA for proposed packaging in a Williams FW14 F1 car



ABOVE The Patriot's turbine exhaust duct

for an IndyCar Lola application too. Where would we be now, eh?

Unfortunately, the vehicle morphed into something that could not achieve its lofty goals. The history books show that I was removed early from the project before it neared physical completion. There were too many egos involved – including mine, I suspect! – and an awful lot of people seemed intent on claiming the credit for it all.

The financial men got involved with disastrous consequences. They were reluctant to add new suppliers to the purchase order database, ignoring the fact that this was an experimental project with very specific needs. They pressured the development team into using existing suppliers, some of whom saw the whole thing merely as a lucrative gravy train.

It all got very political and the conflict within the programme was betrayed on occasions, not least when the Patriot 'tested' for the cameras and a timely PR boost at Donington Park. There was concern at the amount of money that was being spent on the project and there was pressure to show that the car was actually doing something. It was towed round the track at Donington and allowed to run down the hill: that's where the photographs of it 'in action' came from!

Sure, the corporation men who became embroiled in the project were bright guys but they lacked the high-level motorsport experience and intellectual investment to make the project viable. I wanted the likes of Reynard, McLaren and Ilmor involved in the integration of the chassis and powertrain. Motorsport engineers are fantastic at taking a technology that is out there and making it work in racing, but the corporation didn't see why the might of Chrysler couldn't do things better than specialist outfits from England.

In those circumstances there was a huge risk that the project would fizzle out. In its original guise, though, with the components specified that had all been developed for previous military applications, I think there was more than a 50/50 chance of it being successful.

Who knows, you might yet see in the very near future a 20-year-old hybrid Patriot at Le Mans that would showcase, in one car, more than all the technologies that Audi, Porsche and Toyota will use between them in the coming years. Watch this space. RT