

## Back on track

Has motor racing lost its relevance?  
GM's former sporting chief has answers

## Particulates

Ricardo develops revolutionary  
measuring technology

## Diesel record bid

JCB unveils world land speed  
contender, supported by Ricardo



# BUGATTI VEYRON SPECIAL

Ricardo supports Bugatti to design,  
develop and manufacture the driveline for  
the Veyron – the world's fastest road car



# "The most advanc

One thousand and one horsepower, sixteen cylinders, seven speeds and over 400km/h – transmission engineering challenges don't come much tougher than Bugatti's fabulous million-euro Veyron supercar. **Tony Lewin** reports on the support provided by Ricardo in the development and manufacture of one of the most sophisticated driveline systems ever conceived

It's the front-cover splash of almost every car magazine in the world. Everywhere, writers are struggling to find new superlatives to describe its astonishing performance. And everywhere the message is the same: this million-euro machine redefines, dramatically and decisively, our idea of what a car can do.

The concept of a road car faster than a Formula One car is no longer fantasy

but fact; thanks to Bugatti, this remarkable display is now seen as achievable with a car that's also elegant, luxurious and refined, and which does not demand racing-driver skills at the wheel.

Bugatti has defied the doubters and proved that 400 km/h and first-class comfort can indeed go together. Yet with expectations so suddenly and so dramatically transformed, it is all too

easy to forget what a monumental technical achievement the Veyron represents. It is especially important to recall that, at the time it was originally proposed in 2000, the idea of the 1001 horsepower sports car seemed a nigh-on impossible technical challenge.

#### **VW chief astounds the industry**

A moment of stunned silence gripped the audience of international





# ed car of our time"

automotive journalists as the crowd of normally talkative reporters choked in disbelief at what they had just heard. The scene was the Nogaro Hilton Hotel in Geneva in March 2000, when correspondents had assembled to hear Volkswagen's then CEO, Dr Ferdinand Piëch, deliver his annual state-of-the-union address to the world's business and technical media: in the middle of a long stream of corporate results, sales predictions and bland technical statistics, Dr Piëch had casually tossed in the number which was to astound everyone – one thousand and one horsepower.

For this, said Dr Piëch, would be the power output of the new Bugatti Veyron sports car. Only the absolute ultimate in power, performance and sophistication would suffice for the

21st century revival of what had in its heyday been the most glamorous marque in the world. "This will be the most exciting and most advanced car of its time, no more, no less," he predicted.

Previously, only a select few racing cars had breached the thousand-horsepower mark. It would clearly be a major technical challenge to feed this power to the road safely enough for drivers with standard rather than competition licences: delivering such stupendous performance with the smoothness and refinement demanded by an elite millionaire clientele was likely to be a bigger issue still.

#### **Bugatti's Heritage**

It is difficult from today's perspective to imagine the awe in which the

Bugatti marque was held during its 1920s and 1930s golden age. Its sports and racing cars were engineered with absolute purity of focus, always light, ingenious and elegant; the integrity of the road-car chassis attracted the very best coachwork builders of the era, producing style landmarks such as the Atlantique coupé and, at the opposite end of the scale, the mammoth Type 41 Royale. In its exotic aura Bugatti was the Ferrari of its time, but with the equivalent of Rolls-Royce luxury, radical thinking from Lotus and hard-wired race heritage from McLaren thrown in too.

Undeniably, the task of reinterpreting this unmatched legend for the 21st century customer has been a daunting one. Accordingly, Volkswagen decided to call upon the

With seven speeds, dual clutches, four wheel drive and an active rear axle, the Veyron driveline (right) is one of the most complex ever built

very best skills on offer among the world's automotive engineering providers to ensure the born-again Bugatti would satisfy the extremely high demands placed on it by customers whose automotive portfolios already include the likes of Bentley, Ferrari, Porsche and Mercedes-Benz.

For the embryo Bugatti division, set up under Volkswagen's Wolfsburg roof pending the completion of the Bugatti Atelier at the marque's famous Molsheim home across the border in France, Ricardo was the natural choice of engineering partner for the transmission and driveline system.

Michael Kodra, Bugatti engineer in charge of the liaison with Ricardo throughout the programme, explains:

"We had already worked with Ricardo on smaller programmes – they built the axles for two different show cars that were presented, and these axles worked perfectly and without any further problems. We also needed a company which could supply us with a gearbox at low volume: most of the other big gearbox suppliers are seeking to make money through volumes, and we can only offer a run of about 300. Thanks to this and our previous experience with them on the W18 and W12 sports car, we decided that Ricardo would be the best company to support us on this job."

#### Ricardo's biggest-ever driveline programme

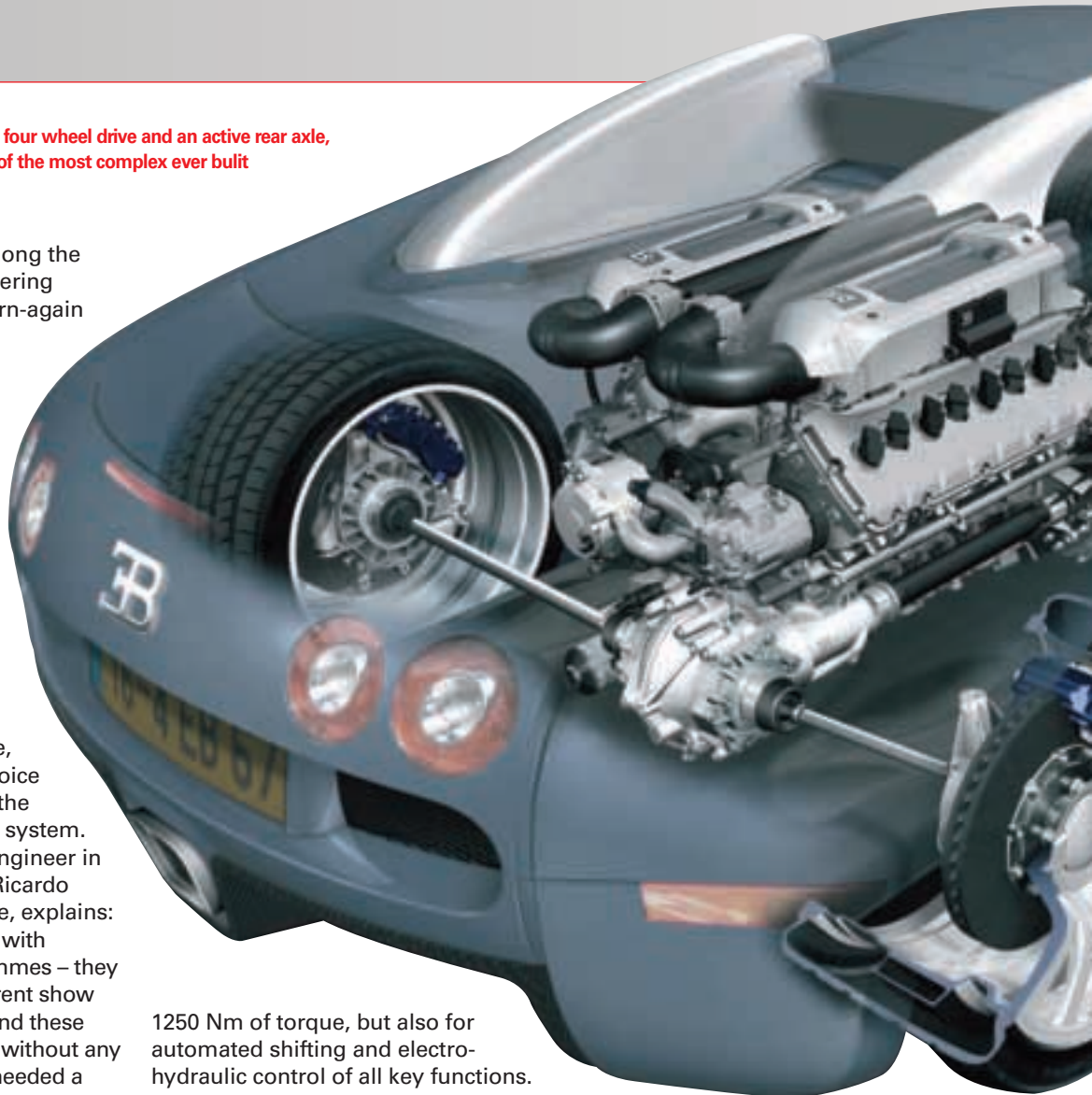
Though Ricardo enjoys an unparalleled reputation in the field of ultra high performance transmission systems across both sports and racing cars (providing drivelines for the Jaguar XJ220, McLaren F1 and Audi's Le Mans winners, for example), once the specification of the Veyron was revealed it soon became clear that the Bugatti transmission system would be much the most sophisticated the company had ever built. As a result, the programme would be the largest ever supported by the company's driveline and transmission engineers.

Bugatti's brief called not just for a seven-speed dual clutch gearbox capable of handling an unprecedented

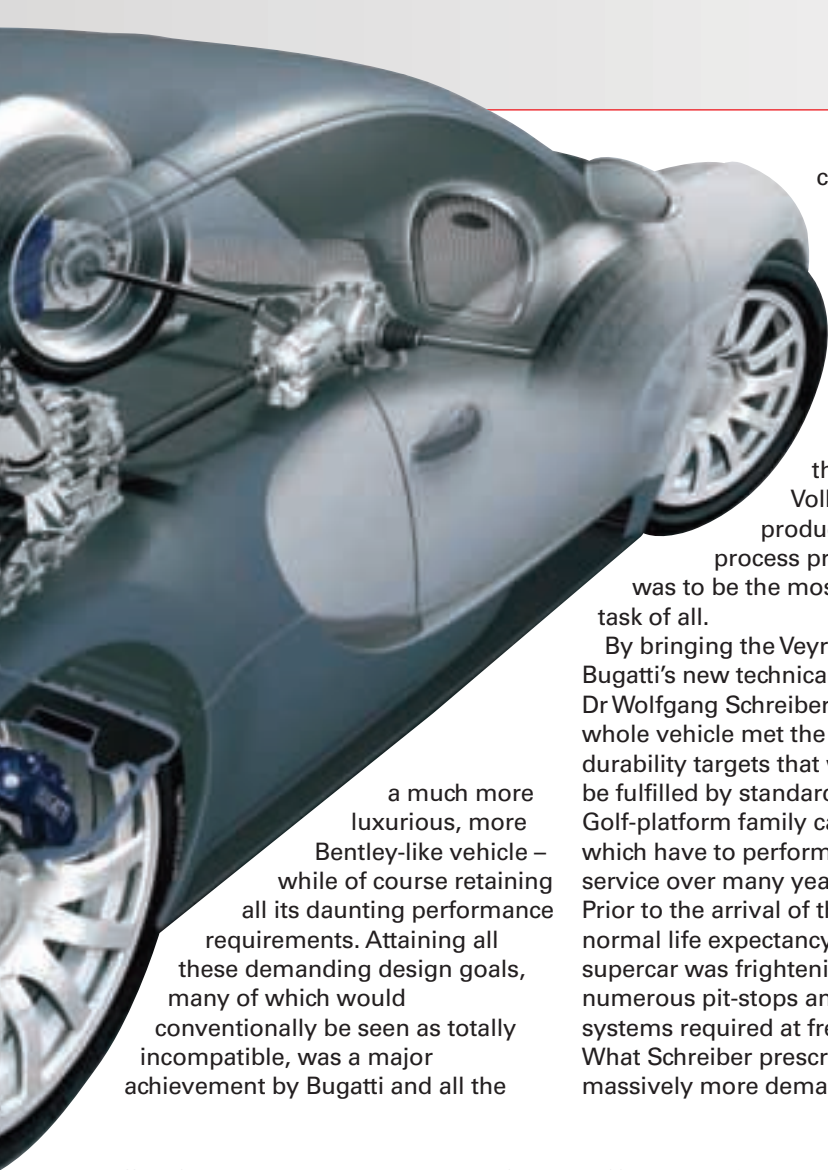
1250 Nm of torque, but also for automated shifting and electro-hydraulic control of all key functions. The driveline, too, was to be of exceptional complexity, with drive to all four wheels, an innovative active rear axle, a Haldex coupling built into the front axle, and all the electronic and hydraulic control systems to

determine not just straightline traction but high speed vehicle dynamics too.

What at the beginning was simply an outrageously fast pure sports car soon found itself doing double duty as







companies supporting the Veyron programme.

Yet, at the same time, the fact that the Veyron programme became part of the mainstream Volkswagen

product development process provided what

was to be the most challenging task of all.

By bringing the Veyron 'in-house', Bugatti's new technical director, Dr Wolfgang Schreiber, ensured the whole vehicle met the same daunting durability targets that would normally be fulfilled by standard million-a-year Golf-platform family cars – models which have to perform faultlessly in service over many years of hard use. Prior to the arrival of the Veyron, the normal life expectancy for a rare supercar was frighteningly short, with numerous pit-stops and replacement systems required at frequent intervals. What Schreiber prescribed was massively more demanding than

a much more luxurious, more Bentley-like vehicle – while of course retaining all its daunting performance requirements. Attaining all these demanding design goals, many of which would conventionally be seen as totally incompatible, was a major achievement by Bugatti and all the

anything ever seen among normally fragile supercars.

The durability requirements make truly terrifying reading for any engineer with an ounce of mechanical sympathy. Given that much of its 50,000 km is driven with the thousand-horsepower engine at full throttle, the Veyron's transmission durability programme must rate as one of the toughest the auto industry has ever devised.

Mike Everitt, senior programmes manager at Ricardo, believes that this regime makes the Veyron the strongest ultra high performance car ever built. "Wolfgang Schreiber has genuinely shifted the goalposts in the supercar segment," he says.

Big-name supercars all too often prove fragile in service. It is rumoured that one model is only capable of doing three full-bore launches before the clutch needs to be replaced. The Veyron, on the other hand, completed 200 consecutive full-throttle launches with consummate ease. "The testers only stopped because it was getting too dark," remembers Everitt. "The clutches were still fine."

**"When exposed to the full 1,250 Newton-metres torque of the 16-cylinder engine, the resistance of the air and even the force of gravity itself seem to have no chance: the EB16.4 Veyron eats up the road as if these physical laws had just been abolished"**

Bugatti publicity, 2003



## MICHAEL KODRA

Michael Kodra is the Volkswagen group engineer in charge of liaison with Ricardo and other key suppliers



### Did the experience with Ricardo gearboxes on the Audi Le Mans winners influence your choice of driveline partner?

No. We started this programme just before the Audi programme became public. Ricardo always keeps its other customers secret, so even we at VW did not know that this work had been done for Audi in the race cars.

### The driveline for this car is very complicated and has a huge effect on the handling and driving characteristics of the whole vehicle. How is it that VW can work together with an outside supplier when it is really determining how that vehicle will drive?

Using the knowledge we have gained through working with Ricardo we have implemented the correct features into the car, such as the rear axle differential, the electronic/hydraulic control, the Haldex coupling which enables us to have four wheel drive, and this dual clutch gearbox. We have been very successful in learning how to calibrate and to optimize them.

### What about the active rear differential?

At that time the rear differential control was something VW had never had in its ordinary cars: we were about to introduce it in the Touareg luxury SUV. This is definitely an item where we needed to have a close look and liaise with these [Ricardo] guys in their work. On the gearbox side, we have done the same gearbox, though much smaller and lighter, for our ordinary passenger ranges such as the Golf. Here, Ricardo learned from VW concerning some software strategies and so on. So I think we both share a little bit, we both learn a little bit.

## Design, development and manufacture

The complexity of the driveline and its control system was such that Mike Everitt and his colleagues at both Ricardo and Bugatti had to bring in extra engineers to ensure the programme would keep to the very demanding schedule set by Bugatti: at its peak, Bugatti's engineering team were supported in the programme by over 50 Ricardo driveline and transmission engineers, with a further 12-15 electronics specialists working on the transmission control system and additional engineers in vehicle engineering too. Two Ricardo engineers even took up residence in VW's home city of Wolfsburg.

"One mustn't forget the absolute enormity of the task that faced Bugatti," explains Everitt. "It designed a car that's not only the fastest and fastest-accelerating car in the world, but one which is technically far more advanced than any of its predecessors.

"It has far more features in it," continues Everitt. "It's four-wheel drive, it is turbocharged, it has an active differential and an active drive transmission system with dual clutches. The car is very sophisticated and is entirely new: new engine, new driveline, new chassis, new everything – and it's attacking the market as the most prestigious sports car ever built. It has been a very formidable challenge."

Even a quick glance at the cutaway of the Veyron driveline on page 10

brings home the scale of the multinational Ricardo and Bugatti driveline team's achievement. There are no fewer than 660 part numbers for the driveline's 1200 components and the system breaks new engineering ground – particularly in its use of seven forward speeds and twin clutches, and in its real-time role in determining high speed vehicle dynamics through its active rear differential and Haldex coupling.

The use of ADAMS simulation modelling of vehicle dynamics allowed Ricardo to provide Bugatti with much necessary data to develop and optimise suspension kinematics, to fine-tune the car's driving characteristics and present a range of options to Bugatti management.

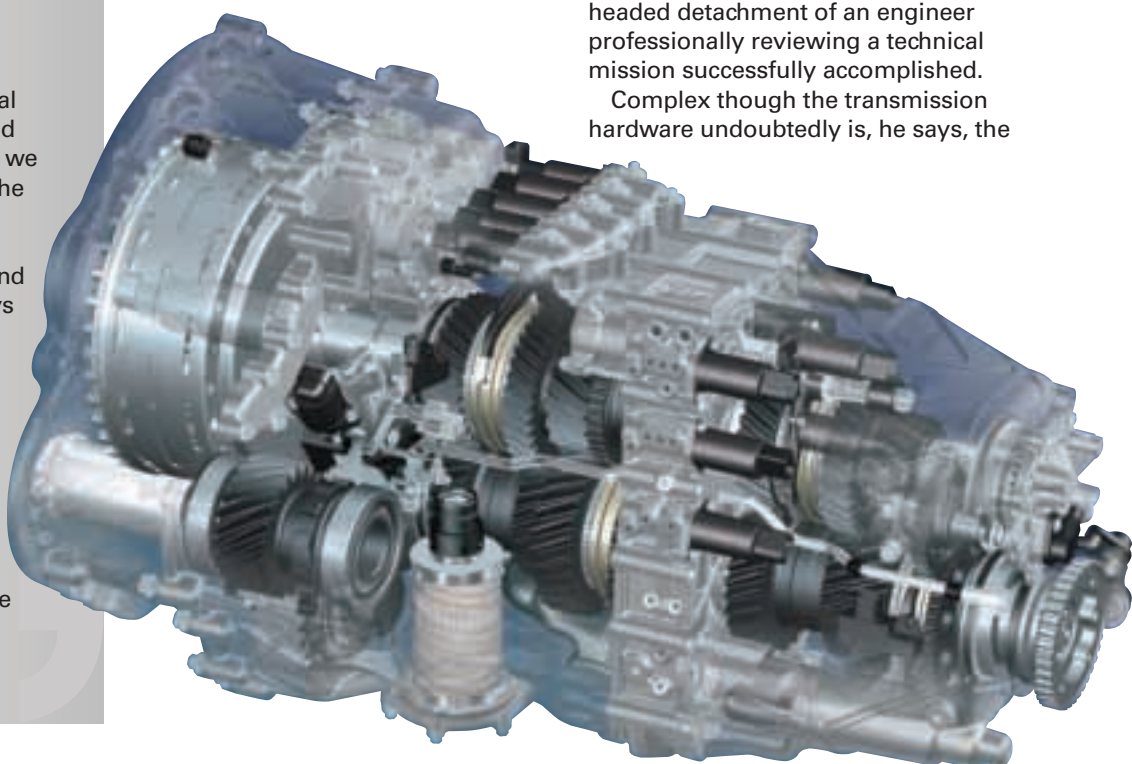
"Bugatti engineers determined what the preferred calibration was to be," says Mike Everitt. "They have been highly successful in calibrating the car in precisely the desired manner, with our assistance. We have helped them give the Veyron the character they were looking for."

## Driving the Veyron

As a key figure in the Veyron development process, Mike Everitt was familiar with the astonishing abilities of the 16-cylinder Bugatti long before the international press was finally allowed access to the car in Sicily in October 2005.

While the assembled correspondents were excited, effusive and often emotional in their comments, Everitt retains the level-headed detachment of an engineer professionally reviewing a technical mission successfully accomplished.

Complex though the transmission hardware undoubtedly is, he says, the





## MANUFACTURING THE VEYRON DCT



Ricardo is no stranger to low-volume, high precision transmission manufacture: its workshops have witnessed the assembly not only of the drivelines for the McLaren F1, Jaguar XJ220 and Volkswagen W12 Nardo record breaker, but also five years of Le Mans winners for Audi and numerous other successful but less well known products. Even so, such is the importance of Bugatti and the complexity of its driveline that a whole separate area of the Ricardo transmissions facility is dedicated exclusively to the assembly of the Veyron system.

Conditions in the Bugatti assembly area are akin to those of a scientific clean room, with each of the driveline's 1200 components receiving a three-stage cleaning process – culminating in an ultrasonic phase – before assembly. Component tolerances are close to aerospace levels at 6-8 microns, and exotic materials include rare-earth magnets located on the gear selector forks for extremely precise position sensors mounted on the external casing to monitor the exact location of selectors. This information is used in the control strategy and helps rule out double gear engagements.

"This is a very high quality, and clearly very high cost operation," says Adrian Turner, manager of Ricardo's low volume production operation, of the manufacturing process. "It's more akin to an advanced prototype build than series production – we call it dedicated cell manufacture."

The cell system sees two technicians each assemble a single transmission a week. Each stage of the assembly process is meticulously documented, with the technician confirming every operation, measuring every tolerance and critical dimension and noting the thicknesses and positions of all shims employed. The multi-page document is held in the Ricardo database so that any in-service problems can be traced back to individual parts of known history.

key throughout is the software that controls it – even though the driver is unlikely ever to sense it doing its job.

Yet even Everitt cannot resist beaming broadly as he revels in the experience of driving the sixteen-cylinder, 400 km/h machine:

"If you are driving the car you just pull a lever and all you see or sense (of the gearshifts) is that the rev counter needle falls or rises: it is slick and smooth but in the background there are a dozen valves controlling key parameters, changing clutch pressures, shifting which gear is engaged and which is the next pre-

selected gear and so on."

One of the key challenges of the gearbox is that it has, on VW's insistence, a non-interlocked gear selection system. This enables super-fast shifts but, in contrast to conventional gearboxes where it is physically only possible to engage one gear at a time, the mechanical arrangement of the Veyron box makes it theoretically possible to engage up to four gears at once. It is a vital task of the control software to ensure that such a damaging occurrence can never happen, and to this end Ricardo specified twin control networks, each running on different software codes, written by different teams using different methodologies. The task of the first is to control the transmission,

while the second continuously monitors it to double check that a double engagement is not about to take place.

Surprising though it may seem for a car of such phenomenal performance, the concept of everything working faultlessly and seamlessly in the background is an important part of the Bugatti's make-up – again making a potent contrast to supercar competitors which can be famously temperamental and tricky to drive.

Mike Everitt describes it as silky smooth and easy. "When the car accelerates it is so fast that if you have a clear road in front of you and you can accelerate up to 150 mph (240 km/h) – which it will do in a matter of a few seconds – it will be up to fourth or fifth gear and you really didn't even count them.

"If you are not watching the gear display change or watching the rev counter needle change, if you're just looking at the road and get to 150 mph and back off, you won't actually know what gear you were in because it does it so smoothly," he enthuses. "Even if you were in manual mode, if you don't do anything the transmission will shift up for you anyway when you reach maximum revs."

### Step-change for VW engineering

From the customer side, VW liaison engineer Michael Kodra is open in acknowledging that Ricardo's expertise has been invaluable:

"I think that by being able to bring this car to the market with its driving behaviour every bit as [good as] we expected it to be, we have done a very good job. Using the knowledge we have gained we have implemented the correct features into the car, such as the rear axle differential, the electronic/hydraulic control, the Haldex coupling which enables us have four wheel drive, and this dual clutch gearbox. We have been successful in achieving a good calibration and optimisation of them."

"The toughest part in most programmes is always the timing," explains Kodra. "Right from the beginning of this job we had a very tight timetable to get this car into series production. You need to remember that almost all the components of the car are brand new – the monocoque and suspension, a complete new engine, gearbox and axles – all the systems have never played together in one car. We had this timetable because the car was

**Left: Complex seven-speed dual clutch gearbox takes one week to assemble at Ricardo's precision manufacturing facility**

**MIKE  
EVERITT**

**Chief programmes engineer Mike Everitt led the work on the Veyron driveline since joining Ricardo in November 2000**



**Ricardo has a lot of experience in high performance transmissions. Can you build on designs you have done in the past, or does it have to be completely new?**

You have to visualize the project as two distinct elements, the first being mechanical and the second the control. For both elements we worked very closely with the VW/Bugatti engineering team to ensure both that they got what they wanted and that we could incorporate their knowledge of specific lessons learned from their own DCT programme in the VW Golf into the programme.

In terms of the mechanical side it is to some extent an analytical and formulaic process, but it is heavily influenced by the experience base that Ricardo and the VW/Bugatti engineering teams possess. Knowing how the transmission needs to be designed for this sort of application, with its very demanding and specialist environment, is something that few companies have experience of, but it is ground on which Ricardo feels comfortable.

The control element of this gearbox was, however, the really innovative side: there are increasing industry and market moves towards dual clutch transmissions because of the benefits you get in fuel economy and efficiency and driver feel. But to do something in this area of performance was quite a challenge: things that work on a "normal" car simply don't just scale up when you get into this class of vehicle.

**When you discuss a programme like this with a customer, who sets out the basic principles? Did VW simply want a transmission for a 400 km/h car?**

No. VW had some quite firm ideas at a feature level – minimum seven gears, very fast speed of shift and so on. Also, the fundamental layout options possible were largely dictated by the defined vehicle architecture, but lots of details were not defined at all. This meant for instance that the gearbox in front and the

rear axle behind the engine was defined, but we explored issues such as whether the rear axle should form part of the engine cylinder block or should it be separate.

**Did you know the power and torque outputs? Did the very high values force you to think differently?**

Yes, we knew the power and torque, but only as headline numbers, and also the wheelbase and the predicted weight. We knew that they wanted it to be four wheel drive and that they wanted it to be active not passive, meaning active differential controls and active torque distribution from wheel to wheel. Most things about this project forced us to think differently.

**Is the transmission seven speed because with a Vmax of over 400 km/h you have to cover such a large speed range?**

Yes: it's also seven speed because reverse is in there as well, giving eight gears in total, with four synchronizers and two gears per synchronizer – so that works very nicely. It also gives a nice even gear spacing on a car that will go seriously fast. Another advantage we had with this transmission was that we could make first gear tall: this car will do its 0-100 km/h dash in first gear.

**In terms of the mechanical design of the system, is it more like a racing car transmission than a road car transmission?**

No: I wouldn't say it is like a race car transmission at all, it is like a race car transmission in the limited sense that it uses race car transmission type materials and very high grade steels for the gears and shafts. It is fully synchronized on all gears including reverse, and all the gears including reverse are fully helical rather than straight-cut. The emphasis on smoothness of shift and pull-away control is absolutely key to the whole nature and character of the car. I think everyone will be amazed at just what a pussycat it can be. You can bumble around at walking pace all day long with absolutely perfect control: you have no juddering, no kangarooing, nothing that many supercars suffer from. It is absolutely the easiest car to drive in terms of the clutch and transmission as can be seen from the many complimentary press reports of the car.

presented quite early on, but as a prototype car."

Such striving for engineering perfection is of course precisely what the Bugatti marque stands for. Mike Everitt cites the example of the significantly raised durability requirements applied from 2004 onwards: new gear tooth designs were employed to ensure they could not only last the distance, but also maintain the level of expected refinement at the end of the 50,000 km durability test. The new gears solved that issue conclusively.

**"Nothing is too beautiful, nothing is too expensive"**

It was with this idealistic maxim that, almost a century ago, Ettore Bugatti founded the company that, like none before and precious few since, was dedicated to absolute purity in design and perfection in every detail. And, though in 2006 the stakes are vastly higher and the regulations governing automobiles are infinitely stricter, there can be little doubt that the re-incarnated Bugatti has produced a








**Veyron speedometer reads up to 420 km/h; left-hand gauge shows horsepower deployed**

model of rare distinction and true engineering integrity – a model which does genuine justice to the Bugatti legend.

Yet, having designed, developed and built what is pretty convincingly the world's fastest, most powerful and most exclusive road car, there is just one cause for regret. No more than 300 examples of the Veyron will be built over its production lifespan;

many will go straight into private collections, while the remainder are certain to lead a pampered existence in air-conditioned garages under 24-hour security guard. So, regrettably, only a few elite individuals worldwide will ever be able to savour the unique experience of 16 cylinders, 1001 horsepower and the sensational return of the most illustrious marque the auto industry has ever known. 

## THE VEYRON IN FIGURES



Engine:	<b>8.0 litre W16, four turbochargers</b>
Power:	<b>1001 hp at 6000 rev/min</b>
Torque:	<b>1250 Nm at 2500 rev/min</b>
Transmission:	<b>Ricardo 7-speed dual clutch; drive to all four wheels</b>
Performance:	<b>0-100 km/h: 2.5 sec 0-200 km/h: 7.3 sec 0-300 km/h: 16.7 sec</b>
Kerb weight:	<b>1950 kg</b>



