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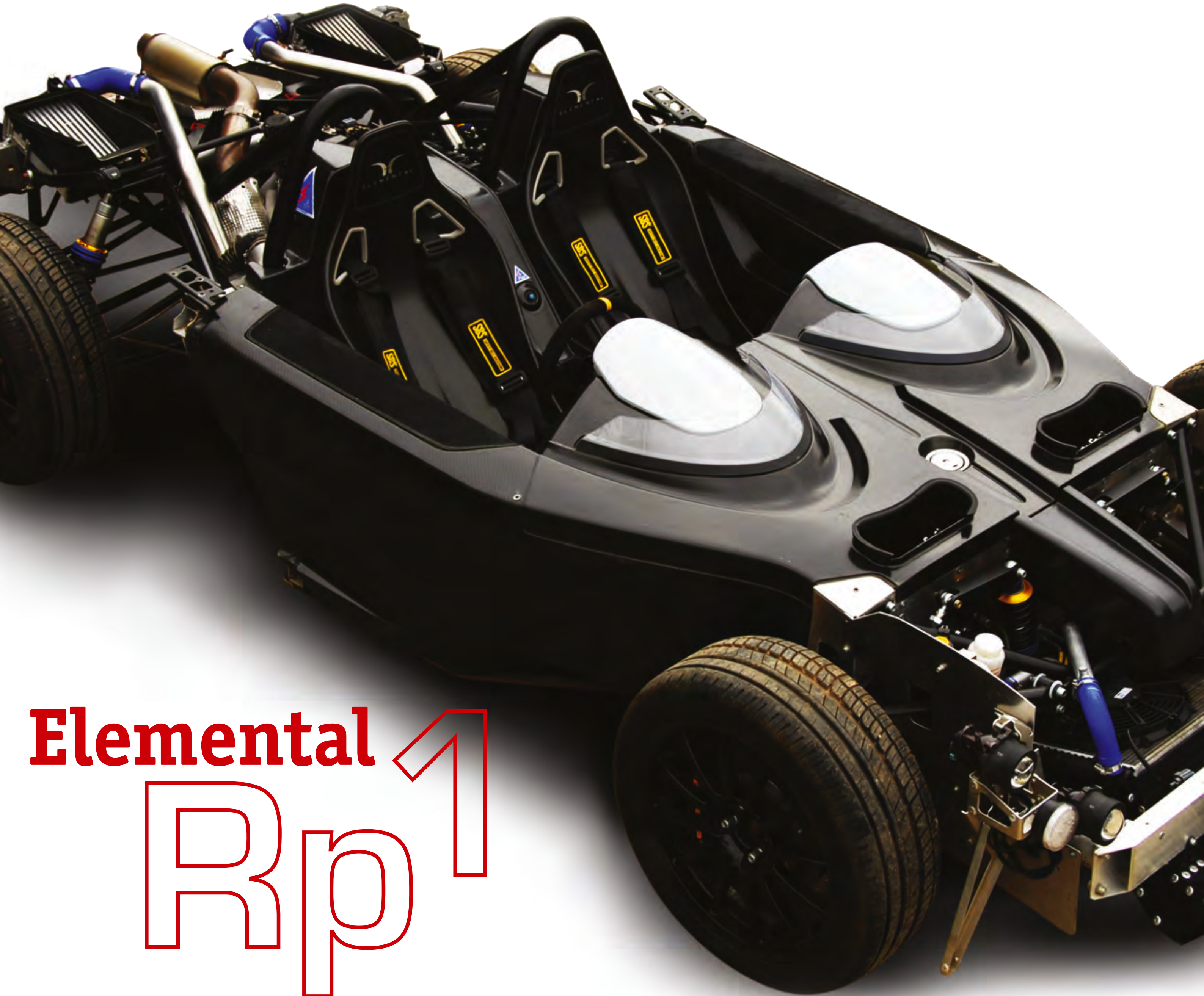

Elemental Rp1

So much more than just another niche British trackday car

Interview: Aston Martin
Following his move from Lotus, Matt Becker, Aston Martin's new dynamics chief, reveals his plans for the marque

Semi-active suspension
Virginia Tech's double-damper, semi-active suspension concept could offer advantages in dynamics

Advanced Urban Vehicle
With an electric twist beam axle and 75° steering angles, could this ZF concept be the future of city driving?

ANNUAL SHOWCASE 2016

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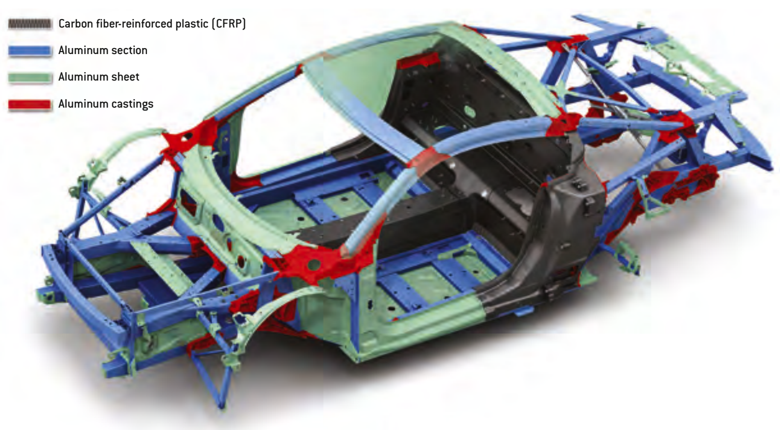

Vehicle Dynamics International
Abinger House, Church Street,
Dorking, Surrey, RH4 1DF, UK
editorial tel: +44 (0)1306 743744
editorial fax: +44 (0)1306 875824
sales tel: +44 (0)1306 741200
sales fax: +44 (0)1306 743755
email: vehicledynamics@ukipme.com

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EDITORIAL
Editor **John O'Brien**
Technical editor **John Miles**
Editor-in-Chief **Adam Gavine**
Production editor **Alex Bradley**
Chief sub editor **Andrew Pickering**
Deputy production editor **Nick Shepherd**
Senior sub editor **Christine Velarde**
Sub editors **Alasdair Morton, Tara Craig, Mary Russell, Lynn Wright**
Contributors this issue
Graham Heeps, John Heider, John Miles, Marc Noordeloos

ADVERTISING
Sales director
Mike Robinson
Publication director
Aboobaker Tayub
Publication manager
Paul Adam

DESIGN AND PRODUCTION
Art director **Craig Marshall**
Design team **Louise Adams, Andy Bass, Anna Davie, Andrew Locke, James Sutcliffe, Nicola Turner, Julie Welby, Ben White**

Head of production and logistics
Ian Donovan
Deputy production manager
Lewis Hopkins
Production team
Carole Doran, Cassie Inns, Frank Millard, Robyn Skalsky

CIRCULATION
contact **Adam Frost**
adam.frost@ukipme.com

CEO
Tony Robinson
Managing director
Graham Johnson
Editorial director
Anthony James

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A NOTE FROM THE EDITOR

For those of you who don't skip over this page on a regular basis, you'll probably be familiar with (or more likely, bored of) my moaning about the increasing influence of electronics within a vehicle architecture. However, a couple of concepts have caught my eye lately that have made me reconsider my opinion of electronics – albeit only if they're integrated subtly.

We cover ZF's Advanced Urban Vehicle concept on page 8 of this issue, but the car's cloud-based driver assistance function to aid parking got me thinking about where the line should be drawn on such technologies. The idea of cloud-based information being fed continuously to the car in real time, constantly adjusting damper rates or other suspension settings, is an expansion of an idea that Koenigsegg dabbled with on the ultra-expensive One:1 hypercar (*VDI*, May-June 2014, p26) and one I find fascinating. The One:1 used 3G in conjunction with the car's suspension to download the appropriate chassis setup for whichever circuit the driver was racing at.

Translating that concept into a more relevant real-world application, such a cloud-based system could be used in conjunction with GPS to govern speed limiters, to help secure a safe first year behind the wheel for new drivers. ZF's conceptual cloud system also takes into account previous journeys, logs the data, and influences the torque delivery on entry into corners – surely extending this capability to all environments isn't too big a leap for manufacturers?

However, having been in a number of new cars recently, the level of personalization available is seemingly on the rise. Multiple steering, gearbox and damper settings are available on an ever increasing number of cars. How many of the settings provide little more than a placebo effect, I couldn't tell you, but I have genuinely struggled to spot many/any changes between some modes in some cars.

The fact that the vast majority of new cars have such options would indicate that the demand to be able to tweak things to be 'just so' definitely exists among consumers. Taking that responsibility away from customers may not be the best idea in their minds, but in my mind at least, the fewer superfluous things there are in a cabin to distract drivers when behind the wheel, the better.

John O'Brien

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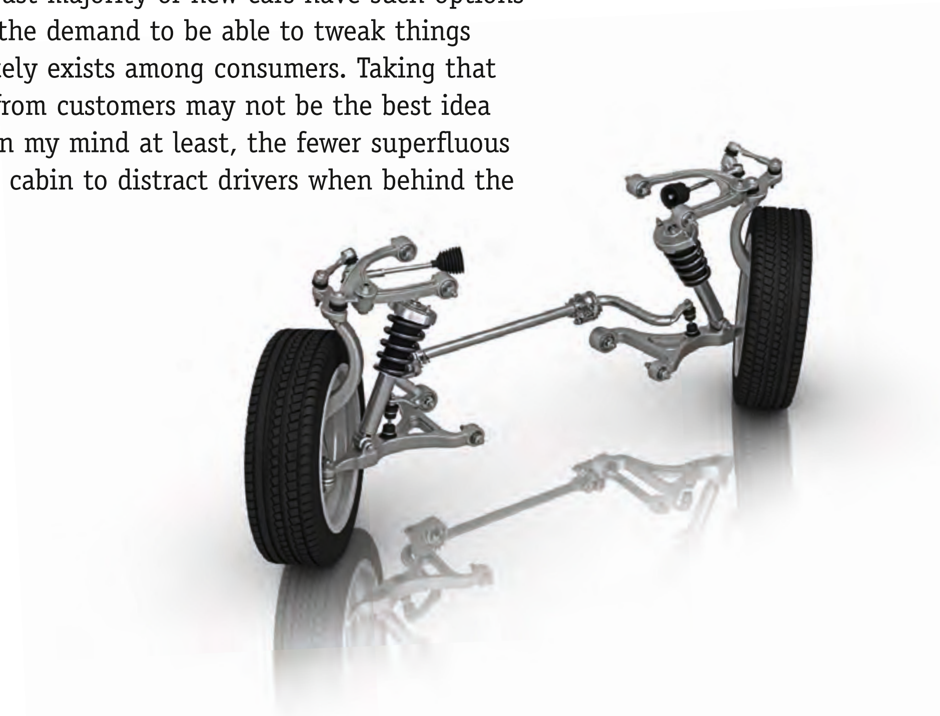
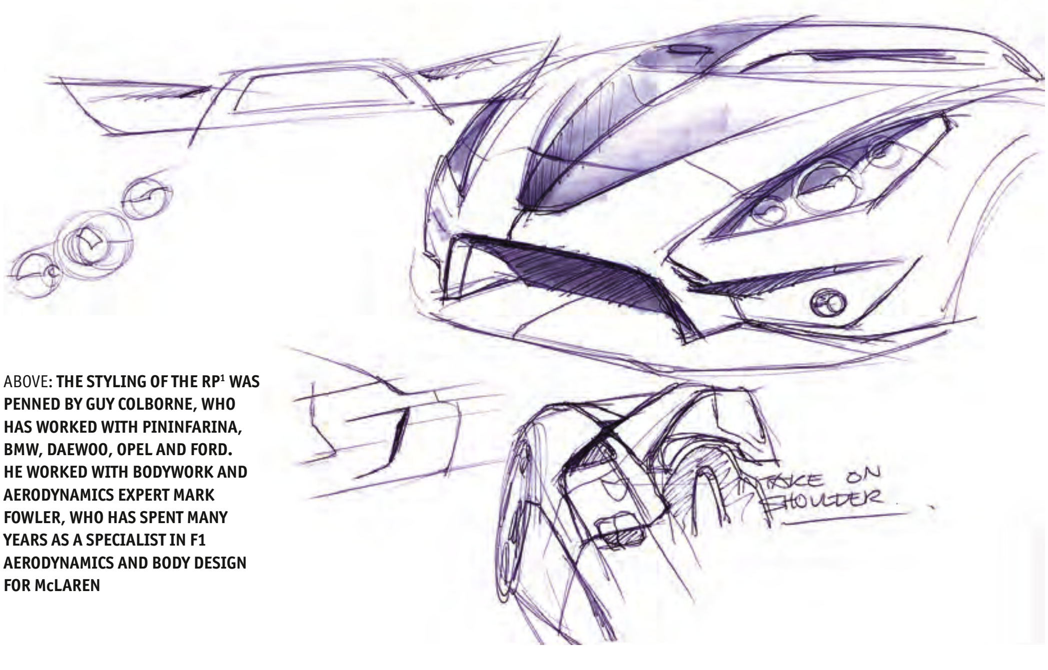


What McLaren's engineers did next

CONCEIVED BY A TEAM OF EX-McLAREN ENGINEERS, THE ELEMENTAL Rp[1]'S ADJUSTABLE DYNAMICS MAY GIVE IT THE EDGE, FINDS ADAM GAVINE



ABOVE: **THE STYLING OF THE RP[1] WAS PENNED BY GUY COLBORNE, WHO HAS WORKED WITH PININFARINA, BMW, DAEWOO, OPEL AND FORD. HE WORKED WITH BODYWORK AND AERODYNAMICS EXPERT MARK FOWLER, WHO HAS SPENT MANY YEARS AS A SPECIALIST IN F1 AERODYNAMICS AND BODY DESIGN FOR McLAREN**

A lightweight, road-legal track car from a small UK startup company – it's a familiar story, and one which doesn't always end in commercial success. However, what makes the Elemental Rp[1] stand out as a credible new entrant to a surprisingly crowded market is the people behind it, a crack team of six that draws on experience from Porsche, AMG, Lotus, Airbus, and McLaren F1 and McLaren's road car projects, among others.

Indeed Elemental's technical director John Begley's passion for vehicle handling and dynamics is matched by his know-how, with his CV including: chassis, suspension and aerodynamic design for the Nissan and Triple Eight race-winning BTCC cars; mechanical and aerodynamic development for the McLaren F1 team; and key roles in the McLaren Mercedes SLR, 12C and P1 programs.

The dream of Begley and his team – who are largely ex-McLaren

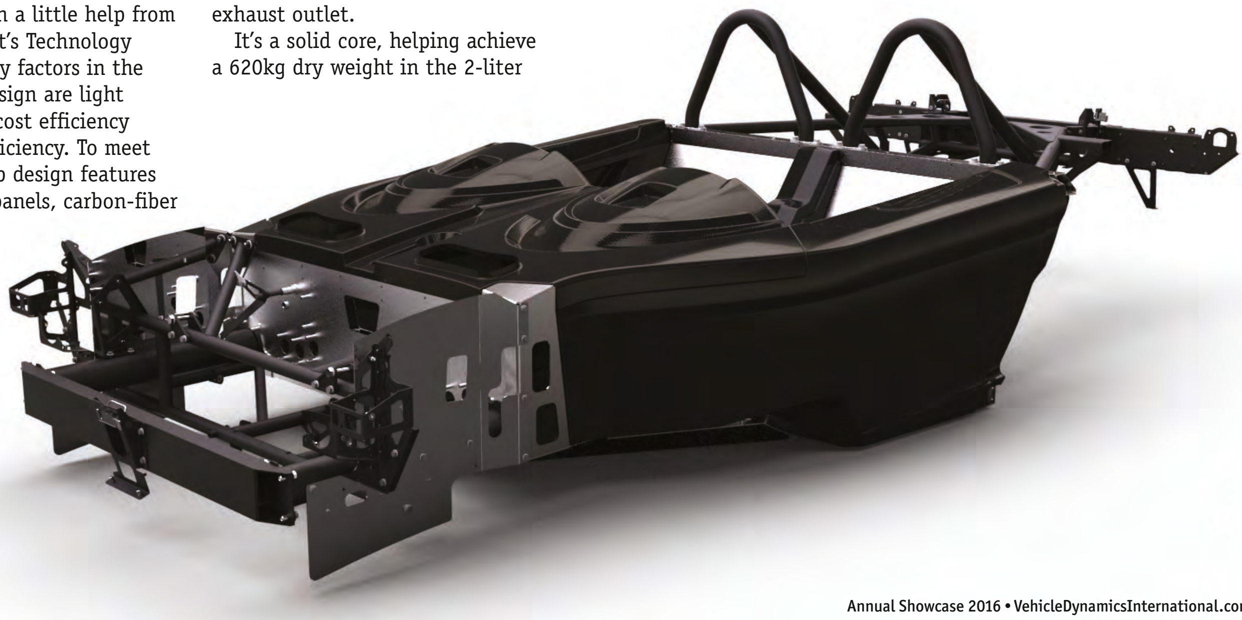
– is to create a track car that can realistically be driven from home to a track hundreds of miles away, with a dynamics setup that can be quickly adjusted to suit its environment.

At the heart of the Rp^1 is a carbon-composite tub, which is exposed mid-ship to save weight and to indicate its sporting intent. The modular tub was developed in-house by resident composites guru Peter Kent, who drew upon his extensive F1 experience, with a little help from the UK government's Technology Strategy Board. Key factors in the patent-pending design are light weight, strength, cost efficiency and production efficiency. To meet these aims, the tub design features aluminum strand panels, carbon-fiber molded panels, an aluminum compound sandwich floor and bulkheads, and carbon composite sidewalls and thwart panel. The head bulkhead carries the mounting points for the front subframe, steering and stay, while the rear bulkhead is the mounting point for the rear subframe and volume hoops. Carbon composite is also used for the beautiful exposed central spine that stretches along the center of the car, from the concealed radiator duct, through the tub between the driver and passenger, and all the way to the central exhaust outlet.

It's a solid core, helping achieve a 620kg dry weight in the 2-liter prototype, which Begley expects to be reduced to 600kg once the structures, layout and materials have been optimized prior to production in early 2016. Early in the project, which began in 2012, GRP was considered for the bodywork, but was soon rejected in favor of carbon composites for reasons of weight and production quality.

ABOVE: **THE PROTOTYPES ARE CURRENTLY UNDERGOING TESTING AT VARIOUS UK FACILITIES**

BELOW: THE ALL-COMPOSITE TUB



SPECIFICATIONS
Elemental Rp^1
Width: 1,775mm (69.9in)
Track: 1,544mm (60.8in)
Length: 3,740mm (147.2in)
Wheelbase: 2,525mm (99.4in)
Suspension: Subframe mounted, long arm, double wishbone (front); gearbox mounted, spun out arm, double wishbone (rear)
Springs and dampers: Eibach springs and Nitron dampers (with race options)
Brakes: Caparo AP four-pot calipers on 280mm vented floating discs
Wheels and tires: Yokohama 215/45R17 with 7x17 Pro Race wheels (front); Yokohama 235/45R17s with 8x17 Pro Race wheels (rear)

Underpinning the tub is a suspension designed for ease of adjustability so an owner can optimize the damper settings, camber and ride height for the drive to the track; and for the track itself, using just a jack, spanners and sockets. This simple owner adjustability is seen as a key selling point of the car, and also extends to the seats, pedals and steering wheel.

The team opted for a double wishbone suspension, with a subframe-mounted, long arm setup at the front, and a gearbox mounted, spun-out arm setup at the rear, with Eibach springs and adjustable Nitron dampers.

Asked about the car's handling characteristics, Begley says that with so much owner adjustability in the camber, castor and toe, it can be whatever the owner wants, with no compromise needed for road comfort or track performance.

"It's race car mentality. The kinematics of the suspension give a very stable roll center and linear camber curves so it is predictable and progressive toward the limit," he says.

Further stability is created by the underfloor downforce dynamics – a claimed 200kg at 100mph – created by large front and rear diffusers. The aerodynamic floor was enabled by a feature that is also claimed to make the Rp^1 a comfortable drive: an F1-style 'feet up' seating position, which freed-up space for the large front diffuser. The design also creates sufficient space between the two front diffuser outlets for the 54-liter fuel tank, which helps achieve near 50:50 weight distribution.

Speaking of weight distribution, the center of gravity (CoG) of the car is located at the driver's CoG. Given the car's weight, the driver's weight becomes an important factor in the car – especially given that a 6ft 6in driver can squeeze in – but by locating the CoG at that point, the balance of the car remains constant, even when a passenger is added, and when luggage, helmets or race suits are carried in the side pods.

That weight distribution remains constant, whichever of the two current engine options is fitted to the rear subframe's 'cassette' longitudinal engine mounting system. The current prototype is powered by a Ford 2.0 liter EcoBoost engine, custom tuned by AER/Life racing to produce 280bhp and mated to a Hewland 6-speed paddleshift sequential gearbox and LSD.

The other engine option – "for the time being", says Begley, with a 999cc Honda Fireblade unit being mooted – is a 1-liter EcoBoost unit giving around 180bhp. The price will be the same for either – estimated at around £70,000 (US$106,000) – but the character will be quite different. Around 30-40kg is saved just through fitting the smaller engine, with further weight reductions expected to result from being able to fit smaller tires and brakes, and a little more weight bias added to the front.

So which version is Begley's Rp^1 of choice? "To be honest, I prefer the 1-liter, which can be more fun at lower speeds and has more character and feel."

Begley explains the price parity is possible because the bill of materials is similar for both. "As a business case there is not much to gain by offering the 1-liter version cheaper. It's more about the characteristics of the car," he explains.

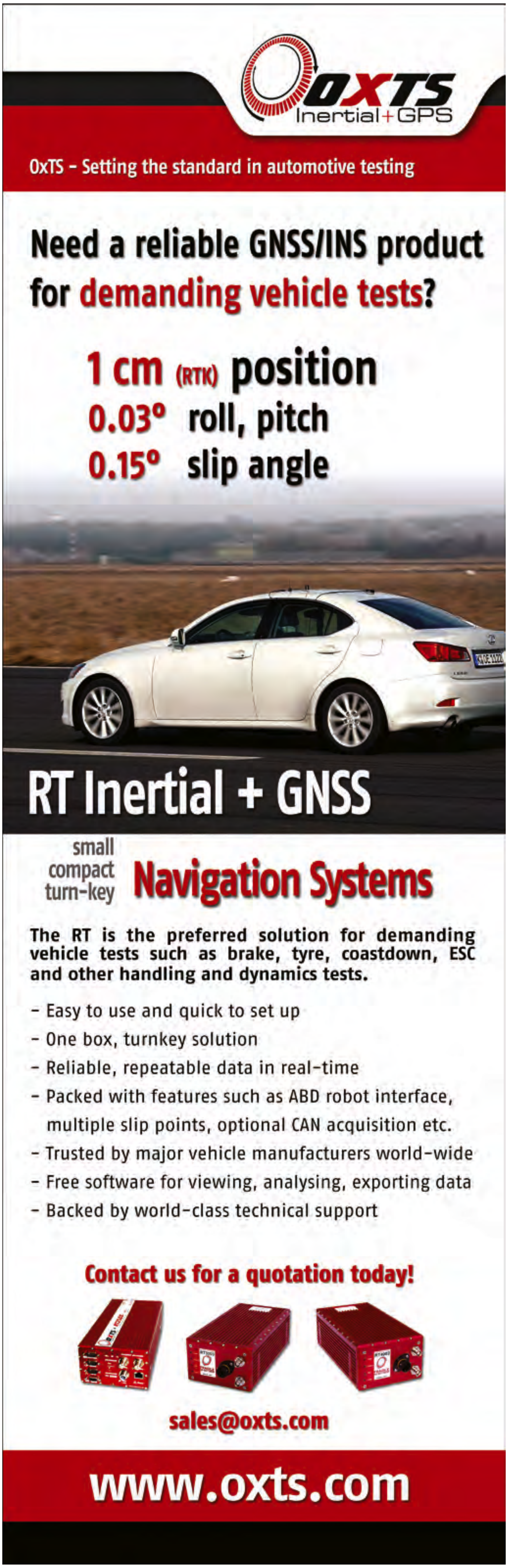
TOP: **RP^1 HAS 7X17 PRO RACE WHEELS ON THE FRONT, WITH CAPARO FOUR-POT CALIPERS AND 280MM DISCS**

ABOVE: **THE CURRENT PROTOTYPES ARE NAMED XP1 AND XP2, A NAMING CONVENTION THE TEAM USED AT McLAREN**

BELOW: **THE MAIN DRIVER FUNCTIONS ARE ALL CONTROLLED BY BACKLIT BUTTONS ON THE QUICK-RELEASE STEERING WHEEL, WHICH ALSO HOUSES THE TWO ELECTRONIC GEARSHIFT PADDLES**

Final pre-production tests are underway at various facilities in the UK, with Elemental's test and development driver David Pittard – also winner of the British Endurance Championship 2012 and a Ginetta GT4 Supercup competitor – reporting that the car is "mega", having clocked 0-60mph in 3.1 seconds, 60-100mph in 4.4 seconds and 100-0 in 4.5 seconds at a recent track test.

Elemental says that several orders have already been placed, with production beginning in early 2016. According to Begley there will be further options in the future for a more track-focused version, with upgraded material options that can save further weight. These include using T45 for the subframe to reduce gauge size while maintaining torsional rigidity.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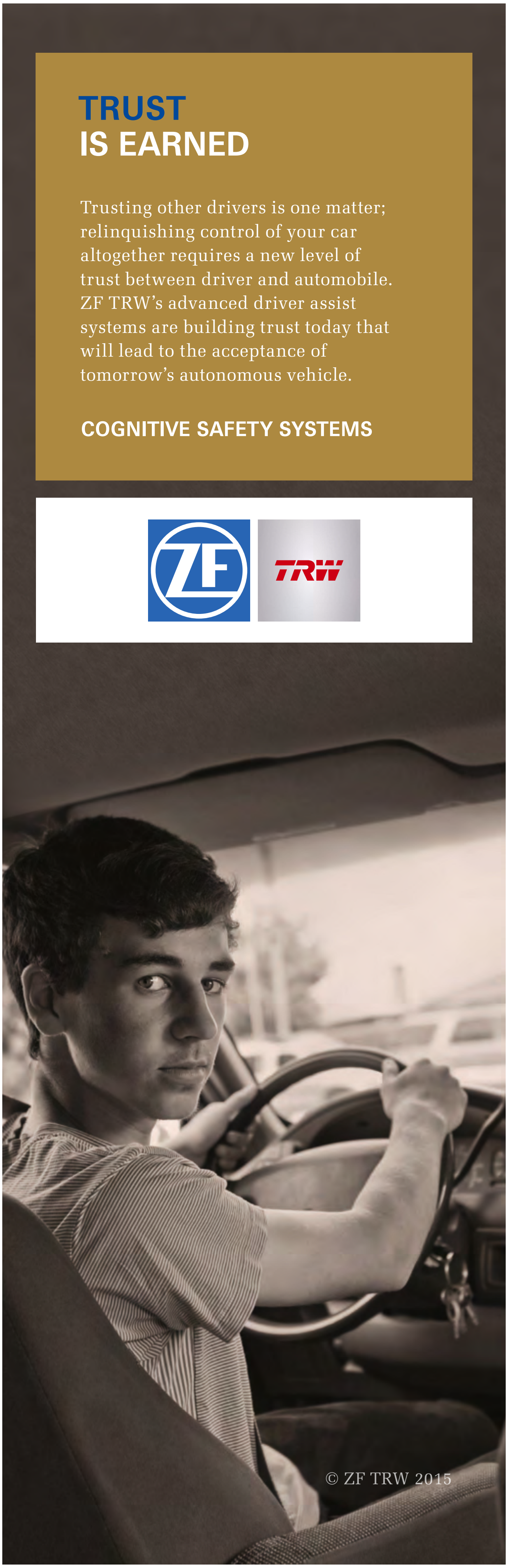
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Tamed beast

THE 2016 AUDI R8 DOESN'T STRAY FAR FROM THE ORIGINAL, INSTEAD INTEGRATING THE LATEST TECHNOLOGIES TO ENHANCE ITS DYNAMIC ABILITIES, SAYS **JOHN O'BRIEN**

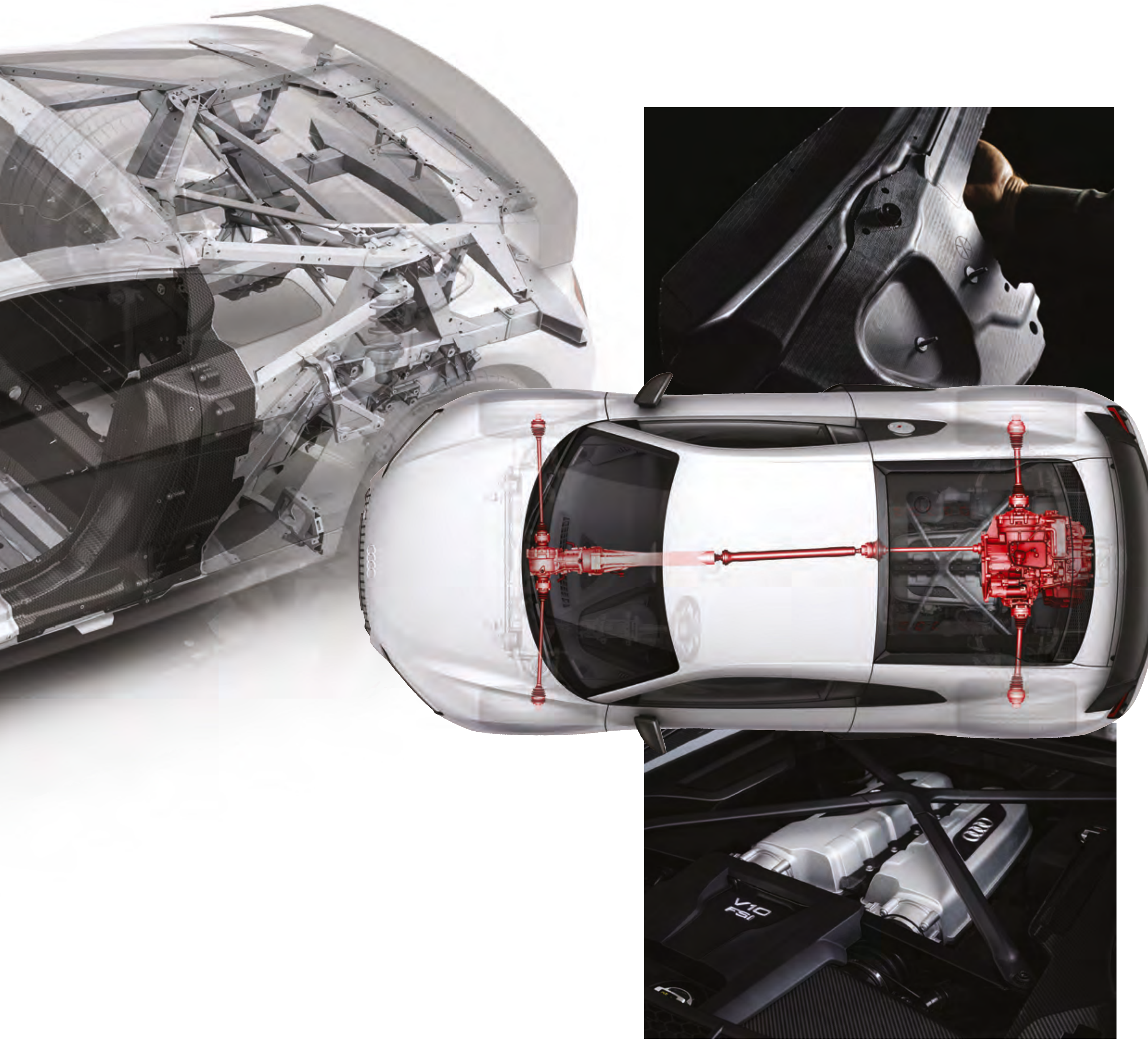
Following the VW Group's acquisition of Lamborghini in 1998, the dynamics team on the first-generation R8 was fortunate to have a good basis from which to start: the Gallardo platform. The second generation of the R8 draws heavily on the template of the very well received original, and keeps its major styling cues.

WHILE THE SECOND-GENERATION R8'S STYLING IS VERY SIMILAR TO THAT OF THE FIRST, MANY DEVELOPMENTS HAVE TAKEN PLACE UNDER THE BODYSHELL

The physical dimensions remain similar too, with the new model just 14mm shorter, at 4,420mm, to reduce front and rear overhangs, 40mm wider (1,940mm), 12mm lower at 1,240mm, while the 2,650mm wheelbase remains untouched between generations.

Like the previous model, the new R8 also has an Audi Space Frame chassis at its core. Now made from a mixed material construction, it weighs just 200kg, which represents a 10kg saving over the original. Audi has achieved the weight saving through the use of the latest aluminum production techniques and the use of carbon-fiber reinforced polymer (CFRP) sections, such as in the cabin's rear bulkhead, center tunnel, and B-pillars.

Each of the several CFRP components that make up the R8's frame are created via resin transfer, but vary in their structure depending on where they are used. For example, in the rear bulkhead, the fiber layers are aligned unidirectionally to support the transverse loading of the car, while the B-pillars have aligned layers to support both longitudinal



and transverse loads. The mixed material construction of the car, and the use of CFRP components, has seen the car's torsional rigidity figure rise between generations, from 40,000Nm/deg to 56,000Nm/deg – an increase of 40%.

Weight reduction was a major focus during the R8's development, with the second-generation car having a dry weight of 1,454kg, 166kg less than its predecessor. Audi states that, had it retained the aluminum production techniques and technology as applied to the first-generation car, the latest ASF would have been 32kg heavier. The new manufacturing techniques are most evident in the frame, with certain sections varying in wall thickness by between 1.5mm and 6.2mm.

Unlike the original R8, which was introduced with a 4.2-liter V8 and later joined by a 5.2-liter TFSI V10, the second-generation R8 is a V10 affair only, but offered in two different states of tune: 540PS and 610PS, the latter being called the V10

TOP: THE CFRP COMPONENTS IN THE R8 ARE CREATED BY RESIN TRANSFER

CENTER: THE QUATTRO SYSTEM FEATURES A REVISED ELECTROHYDRAULIC MULTIPLATE CLUTCH IN THE FRONT DIFF

ABOVE: THE V8 OPTION IS GONE, WITH TWO VERSIONS OF V10 POWER AVAILABLE: 540PS OR 610PS

Plus. Mounted ahead of the rear axle, the engine is placed on the vertical axis of the car's center of gravity, to help achieve a weight distribution of 42:58. The engine's power is transferred through a redeveloped quattro system, which varies torque distribution to each individual wheel, based on the driving situation, driver input and ambient conditions.

The 2015 quattro system features a revised electrohydraulic multiplate clutch in the front differential, which distributes torque between the front

SPECIFICATIONS

Audi R8 V10 (V10 plus)

Dimensions: 4,426mm (L) x 2,037mm (W inc. mirrors) x 1,240mm (H). Wheelbase: 2,650mm. Track width: 1,638mm (F), 1,599mm (R)

Dry weight: 1,454kg

Powertrain: 5,204cc V10. 540PS @ 8,250rpm (610PS @ 8,250rpm), 540Nm @ 6,500rpm (560Nm @ 6,500rpm)

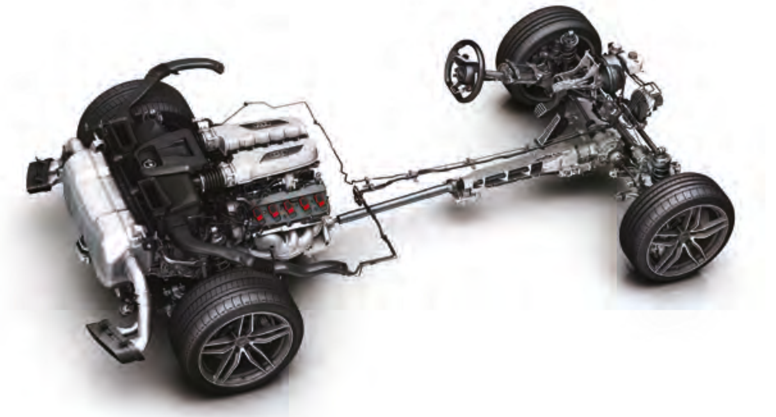
Steering: Electromechanical variable assistance, 15.7:1 ratio. Optional 'dynamic' steering, variable ratio between 10.0:1 and 17.5:1

Brakes: 'Wave contoured' 365mm (F), 356mm (R) discs. Eight-piston calipers (F), four-piston calipers (R) (380mm carbon-ceramic (F))

Wheels: 19 x 9J (F), 19 x 10.5J (R)

Tires: 245/35 ZR19 (F), 295/35 ZR19 (R)

Performance: 198mph top speed. Acceleration 0-62mph 3.5 seconds (205mph top speed. Acceleration 0-62mph 3.2 seconds)



LEFT: THE NEW R8'S STEERING HAS SWITCHED FROM HYDRAULIC TO ELECTROMECHANICAL

INSET: THE V10 PLUS MODEL HAS A LARGE, FIXED CFRP REAR WING, INSPIRED BY AUDI'S DTM WORK

ABOVE: THE LMS VERSION HAS THE SAME CHASSIS

wheels with no fixed distribution, with up to 100% of the torque being diverted to either wheel at any time. The first-generation car's viscous central coupling has been replaced with another multiplate clutch arrangement, while the rear differential remains a purely mechanical locking unit, which allows for 25% locking effect in traction, and 45% in thrust.

The quattro system is connected to the engine's coolant circulation system, which uses three large radiators at the front of the car to ensure the entire system does not overheat under prolonged use.

Despite the common underpinnings of both performance variants, the two models are separated in their respective suspension setups, with the V10 Plus having a stiffer spring and damper combination, with increased ride frequency. The optional Audi magnetic ride, available on both models, remains based on Delphi's MagneRide magnetorheological dampers. All three damper options are paired to double aluminum wishbones all round, which feature revised rubber-metal mounts and transverse link mounts.

Perhaps the biggest change to the R8 is the switch from hydraulic to electromechanical rack assistance. In the 'lesser' V10, the system operates with a fixed ratio of 15.7:1, while the optional dynamic steering function uses superposition gears to continually vary steering ratio as a function of vehicle speed between 10.0:1 and 17.5:1. This is overridden by the performance programs, which have a fixed ratio of 13:1.

Both variants of the R8 come equipped with 19in lightweight alloy wheels, which are shod in 245/35 front and 295/35 rear Pirelli P Zero tires. Behind these big wheels, on the 540PS model, sit 'wave-shape contoured' cast-iron brake discs – 365mm front, and 356mm rear. These are paired to eight-piston fixed calipers at the front, and four-piston calipers on the rear.

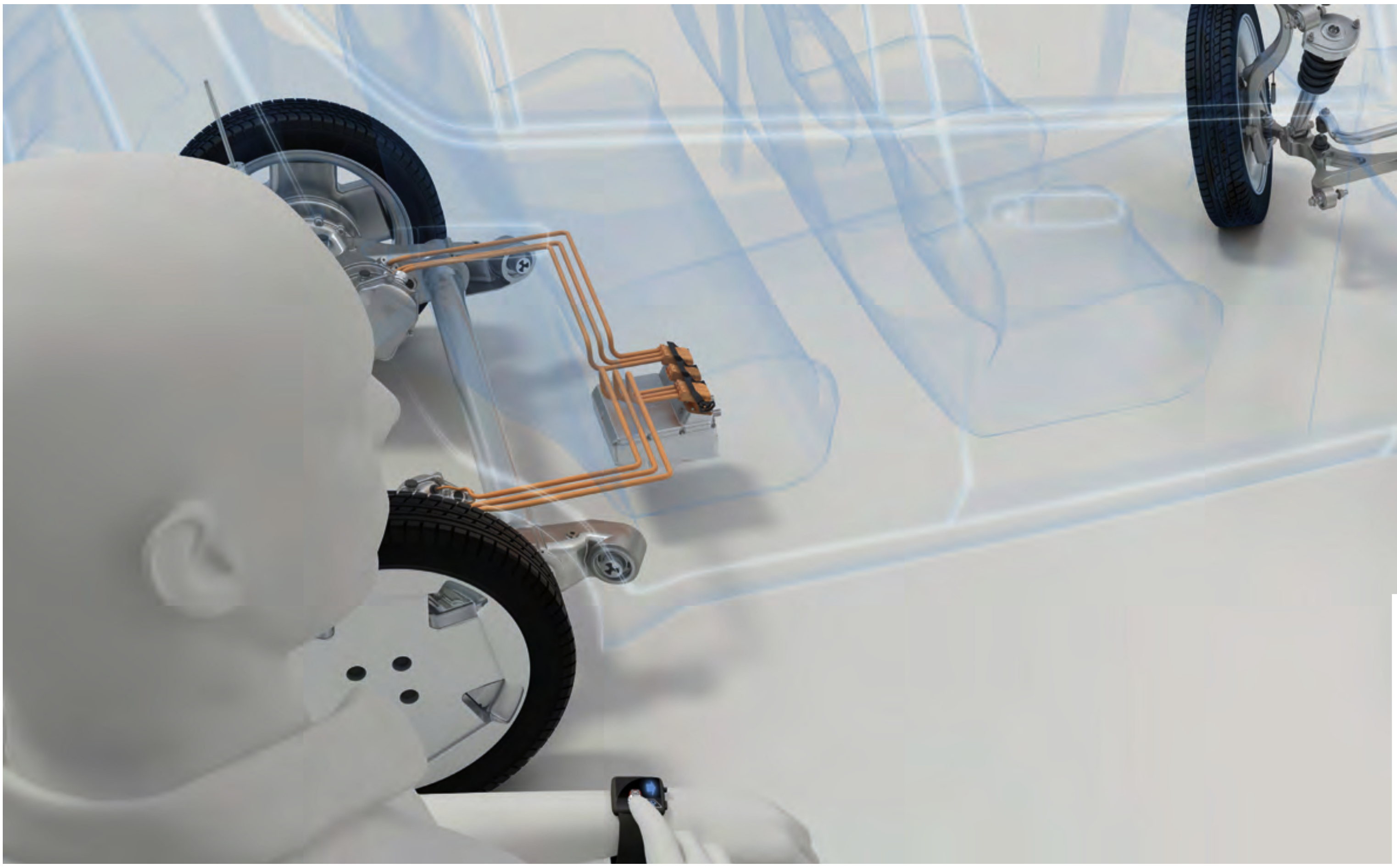
The V10 Plus gains carbon-fiber-reinforced silicon carbide brakes, which despite their increased diameter at the front (380mm) weigh 15.2kg less than the steel equivalents. Operating on the brakes is Audi's ESC system, which offers a torque vectoring functionality in addition to its influence over the ASR and ABS control systems.

Audi's R8 LMS race car is taken from the same production line as the R8, and the company is keen to highlight the links between the two; a notion it furthered by introducing the race car before the road car version. Drawing from experience gained in GT3 racing, the second-generation R8 is able to generate 140kg of downforce at its top speed of 205mph, which is split 100kg over the rear axle and 40kg over the front. This has been achieved on the R8 V10 Plus via a large fixed-position CFRP rear wing that Audi says takes its profile from its DTM race cars, while on the 540PS model, the spoiler is electrically extended at 74mph.

Working in unison with these aerodynamic devices is a rear diffuser that is fed by two venturi tunnels on the car's almost completely flat underfloor, which feed air over a number of longitudinal rib channels that distribute it evenly.

VDI SAYS

The V10 Plus made quite an impression on *VDI*, while out on the rain-soaked roads of southern France. Head online to hear our driving impressions of the 2015 Audi R8 V10 Plus



City slicker

ZF TRW HAS UNVEILED ITS VISION OF URBAN TRANSPORT, BASED ON AN EXISTING CITY CAR, BUT MODIFIED TO MAKE CITY LIFE THAT BIT EASIER. BY **JOHN O'BRIEN**

REMOTE CONTROL PARKING PERFORMED VIA SMARTWATCH IS JUST ONE INNOVATION IN THE ADVANCED URBAN VEHICLE CONCEPT

The original Mini, as penned by Sir Alec Issigonis, was a revelation when it burst onto the automotive scene in 1959. Its compact design was a triumph in efficient vehicle packaging, and is a concept that is still used today.

Unveiled with a little less fanfare this year, but carrying some equally clever packaging ideas, is the conceptual Advanced Urban Vehicle from ZF TRW. Based on Opel Agila/Suzuki Splash underpinnings, the concept ditches the original powertrain and suspension and replaces them with ZF components designed to make urban commuting easier. This also sees the car switch from front- to rear-wheel drive.

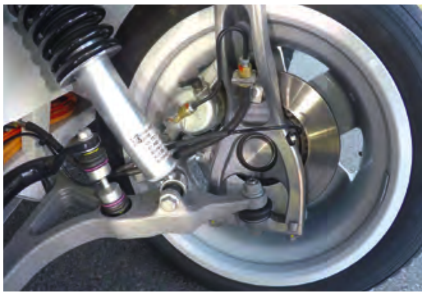
That altered powertrain orientation has helped facilitate the car's increased maneuverability as the standard car's front driveshafts have been removed. The Agila/Splash's steering column and MacPherson struts have also been replaced with prototype parts from ZF.

"At the front axle we have implemented a new concept that enables steering angles of up to 75°," explains Dr Harald Naunheimer, head of corporate research and development at ZF. "The innovative chassis concept substantially reduces the steering effort required during parking and turning maneuvers."

The suspension is designed to deliver double the steering angle achievable by the standard base car, through the use of double-pivoted upper wishbones and jointed rack tie rods. Once the conventional steering angle has been achieved, the additional links between the steering rack and the upright allow the increased angles.

The lower wishbone remains relatively unchanged, with a damper and anti-roll bar mounted in a conventional manner.

"The increased steering angles can potentially wear the tires more, but most problems with tire wear are a result of dynamic driving," adds



Naunheimer. "We could do 50km/h with the tires angled at 75°, but the risk of instability is greatly increased, so we have made some limitations to the steering system so that the angle halves at speed."

This twofold approach to the steering angle means that the turning circle of the Advanced Urban Vehicle is just 6.5m. For comparison, the base Agila/Splash requires over 9m for the same maneuver, while the Smart ForTwo requires 7m.

At the rear, the standard torsion beam axle is replaced with ZF's 'eTB', or electric twist beam. The major difference between the two, as the name would suggest, is the integration of a motor controller pack in the center of the axle.

ZF states that the concept of the eTB was to deliver an electric car driveline that is integrated into a semi-independent rear suspension. Working in conjunction with the central electric motor controller are two 40kW compact drive units – one integrated into each wheel hub. Delivering axle torque of 1,400Nm and a maximum 21,000rpm, the city car can reach a top speed of 150km/h. The eTB's main steel section is connected to the aluminum trailing links using a polygon press-fit connection technique, which in conjunction with other aluminum features (such as the electric motor's housing) means the complete unit weighs just 45kg.

The electric motors at the rear hubs mean that the eTB is also able to offer wheel-specific torque vectoring for the appropriate yaw dynamics at higher speeds. In urban areas, torque vectoring is used in conjunction with the new steering arrangement, effectively enabling the car to pivot on its inside rear wheel when completing a tight parking maneuver.

ZF is keen to highlight that the benefits of the unit extend to the car's packaging and overall weight. The integrated electric motor means that no additional subframe or cradle is required to mount the drive unit, while the positioning of the two electric motors means that driveshafts are no longer required.

Despite most small cars using a torsion beam rear setup, a sector in which ZF claims over 90% of the market, the brand also states that the eTB concept is to be rolled out as a modular unit, enabling installation in front-wheel drive and larger mid-sized luxury vehicle applications in the future.

THE 75° STEERING ANGLE ON THE FRONT WHEELS MAKES THE ADVANCED URBAN VEHICLE IDEALLY SUITED FOR DRIVING AND PARKING IN THE CITY

By retaining conventional pick-up points, the eTB can be retrofitted or installed into existing production vehicles with relative ease. ZF states that it is even possible to retain the original vehicle's braking system and wheel rim dimensions, with no modification required.

The all-new hardware in the Advanced Urban Vehicle is complemented by software concepts such as cloud connectivity, under the name Cloud Assist, which controls the electric motor's output in relation to geographic location and road topography. When the driver needs to park, they can do so from within the car, or by remote control using an app, a smartphone, a tablet or a watch.

BALDRY PREVIOUSLY WORKED AS A DESIGN ENGINEER WITH WILLIAMS F1 BEFORE SETTING UP JUNO RACING CARS IN 1999. IN AUGUST 2014, GINETTA CARS ACQUIRED JUNO AND BALDRY BECAME TECHNICAL DIRECTOR FOR GINETTA

Two minutes with...

...EWAN BALDRY, TECHNICAL DIRECTOR, GINETTA CARS

How does a typical Ginetta development program work?
We'll design parts in isolation on the CAD system and then have at least one prototype manufactured.

Our first stage of on track testing is done at a facility very close to us, which is the old Church Fenton RAF base (now called Leeds East Airport) in West Yorkshire, UK, and we have a garage facility there. We've converted a section of the old runways, and a support network of roads to the runways, into a small test track, which has a range of corners and straights that provide a good challenge for the cars. The tests often lead to another stage of iteration, but once a car is signed off, it's taken to the track for one final check and sign-off.

Does Ginetta have any on-site chassis testing facilities?
We have a rolling road dyno as well as an engine dyno in-house. In terms of chassis work, we most often make use of the Multimatic's seven-post rig in Thetford, UK. We regularly put cars on there and run through various frequencies and monitor the excitation of the car to achieve the best level of performance.

Do you aim for maximum performance in the model range?
No, I think they're all very different. The G40 is quite a raw, agile experience that is almost a modern interpretation of the classic 1960s sports car. We're very clear on the positioning of our road cars – they are race cars that you can drive on the road.

With our race cars, the G55 delivers a moderate level of aerodynamic performance, while the GT3, which is essentially the G55 on steroids, has a much greater aero dependency. Taking that to the next level is the G57, which has a very high performing aero package that dominates the car. But when you have a car that gets its performance through an aerodynamics package, you do have to compromise on suspension – particularly ride comfort – as you need to ensure the aero platform is stable enough so that it can deliver good, constant performance throughout a lap.

How do you find the right balance of sportiness and comfort for road cars?
Ride and handling are always the compromise. Put something like the G57 on the road and it would have reasonably good handling, but terrible ride comfort, simply because you compromise that comfort in exchange for responsiveness and the ability to change direction quickly.

For example, take something like a Citroën DS on hydrolastic suspension, or a late 1970s American car: if you imagine either trying to negotiate a chicane, there's a long time delay between the first steering input being made and the car responding, as there is a lot of movement, and that movement takes time. When you get to the core of the chicane and make the left-to-right transition, the steering input is followed by another delay as everything is slowly reacting to the changing side loads on the vehicle. Yes they ride well, but we focus on the complete opposite.

Do you see electronic driver aids as a good thing or a bad thing?
I'd say it was horses for courses; we don't use any on the G40 at all – no servo assistance on the brakes, no power steering, so there's that real raw connection to the car. The G55 gains power steering, but still no traction control. That's mainly because once the aero loads start to build a little bit, and it runs on a wider slick tire, the loads become too great to try and physically handle it without assistance. But, as soon as you add that assistance, you start to detract from the connection. But, as with most race cars, we chose the G55's system to ensure that there was still reverse feedback through the column and wheel.

Moving on to the GT3 and the G57, you are working with big levels of power, and to fully exploit all of that, we introduce some level of traction control. And while I think purists would like to avoid that, the reason why its more and more accepted is because the guys who are paying the bills in motorsport – which is generally keen amateurs – don't quite have the skill level to get the most out of it without some form of driver aid. The GT3 also has ABS, because a big expensive car like that is expensive to repair, should it end up in a wall. The aim is to give drivers something they can jump into and drive quickly in a relatively short period of time.

THE G60 ROAD CAR ACHIEVES A WEIGHT FIGURE OF 1,080KG THROUGH THE USE OF A CARBON-FIBER SKIN ON A TUBULAR STEEL CHASSIS

Turn the page to read what John Miles has to say about Ginetta

On the job

JOHN MILES TAKES A BALANCED APPROACH TO THE PROBLEM OF WEIGHT DISTRIBUTION, AND CONSIDERS THE PERFORMANCE OF LEFT-HANDED CARS ON RIGHT-HANDED TRACKS

The 750 Motor Club came to prominence in 1939 and specialized in very low-cost motorsport, specifically creating the 750 Austin 7- and 1172 side-valve Ford-based formulae for amateur-built racing cars. Humble yes, but important because the 750 Club is where Colin Chapman (Lotus), Eric Broadley (Lola), Gordon Murray (McLaren), Tony Southgate (BRM/Shadow/Arrows), Len Terry (Lotus/Eagle), and many other talented designers cut their teeth.

The 750 Formula regulations specify a 1108cc Fiat Fire engine with a mandated cam, with tuning, induction, weight (up to 375kg) and tires all tightly controlled. Layouts are generally free, including aerodynamic devices.

Today, just like when the club began, there are no big budgets, so it is a question of design and build talent and scrounging technology where you can. Equalizing weight distribution both front to rear and side to side with the driver on board is crucial.

The critical nature of weight distribution – with driver aboard – became apparent at a recent four-post rig test featuring a current left-hand-drive Ginetta G55 GT4 race car at the Multimatic facility in Norfolk, UK. The main driver complaints were oversteer and nervous rear axle behavior under braking, so with the front roll stiffness already at its maximum, the front ride height was increased in an attempt to optimize balance. The passing comment that at Spa the car went faster with ballast in the right-hand side chimed perfectly with finding a 40kg cross weight measured at the rear axle.

Critical circuit performance metrics taken from 50 outputs from the MTCE rig include the symmetry rating and the contact patch load variation, measured during standard 0.5-30Hz swept-sine excitation runs. The symmetry rating in particular is designed to highlight any dynamic changes in cross weights that occur during symmetrical heave inputs to all four tires. These tests showed that the car had large roll and warp loads, with no roll taking place at all, which in turn explained the variable response and grip levels in left-to-right corners.

Further discussion with the customer – sister magazine *Professional Motorsport World* (PMW) which has a team competing in the 2015 Avon Tires British GT Championship with a G55 – revealed that a clutch-type LSD was fitted, which I know can work to a team's disadvantage, because the across axle pre-load (friction) varying upward from around 80Nm can create an unintended yaw moment if one rear tire loses grip in split low-mu conditions. Since grip depends on vertical load, which is minimized under braking at well over 1.0*g*, any cross weighting spells trouble, especially if compounded by the rear dampers, which in this case had too much rebound control – inhibiting rear wheel 'droop' on fierce braking – and were differentially adjusted.

"Equalizing weight distribution both front to rear and side to side with the driver on board is crucial"

Once the front height was set back to standard specification and the other maladjustments sorted out, we were left with the question of whether to suggest adding mass to make the car properly balanced but 40-50kg too heavy, or to run the car without the weight. In the event it was run with 40kg, with the drivers reporting that the weight created the best stability and handling they had experienced in the car but, unsurprisingly, a lack of performance on the straights. So it is no surprise that LHD race cars are usually built from scratch with minor masses positioned to equalize side-to-side tire loadings. Where fore/aft mass distribution is concerned, the same laws apply. When Team Lotus installed the heavy 3.5-liter Mugen Honda V10 in the 1994 Lotus 107 designed around the Cosworth HBV8, the only change made to prevent this weight from creating over-steer was to install a 75mm spacer between the gearbox and the engine, thus moving mass forward and helping to unload the rear tires.

So given equalized weight distribution, is left-hand drive really a disadvantage on the UK's predominantly right-handed tracks? I believe so, especially on a lightweight car, simply because the driver's mass is higher than the balancing ballast, and therefore cornering dynamics or lateral acceleration come into play, multiplying mass CoG effects on the greater number of right-hand corners and potentially reducing average weight transfer per lap. And as we all know, reductions in mid-corner weight transfer mean that the inside tires will do more work, and that means more grip.

LMS solutions for driving dynamics

Balancing vehicle handling and ride comfort using real-time modeling technologies

Car body flexibility influences the handling performance, including the subjective driving experience. Traditional approaches, such as body static stiffness tests, can objectively quantify the effect of reinforcements into a single static stiffness value. But when evaluating on the track in operational conditions, objective global vehicle performance quantities typically don't show significant changes for different body variants. Consequently, the possibilities to understand how body stiffness changes can impact the vehicle performance are limited.

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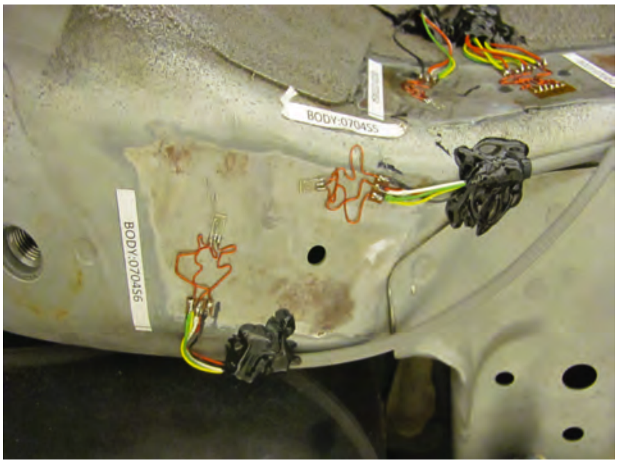

Thanks to the expertise of LMS Engineering, automotive OEMs can visualize body deformation during handling maneuvers, and decompose it into contributions of global body deformations.

Realize innovation.

Feeling isolated...

THE INTEGRATION OF ALTERNATIVE POWERTRAINS IS RESULTING IN SOME ODD DYNAMICS, SAYS JOHN HEIDER

Mother Nature has blessed us with four major appendages with which to control the dynamic performance of a modern passenger vehicle: two arms with hands to control the direction of the vehicle; and two legs with feet to control the speed at which the vehicle progresses over the road surface. The role of our arms and hands has remained virtually unchanged from reins, to steering tiller to steering wheel. The role of our legs and feet has also remained largely the same, albeit the position of clutch, brake and accelerator pedals took some time to become standardized in the early part of the 20th century. Unfortunately for the left foot, its role in operating a clutch pedal is becoming increasingly rare in the mature automotive markets of the world and it is now solely the responsibility of the right foot to control the vehicle dynamics attributes of acceleration and braking.

When electrically assisted power steering systems became a viable alternative to hydraulic, OEMs and suppliers faced many hurdles in attempting to preserve the feel and precision of a hydraulic system, while exploiting the inherent benefits of an electric system. This transition from hydraulic to electric has largely been successful. Average customers are not aware of any difference between their old and new vehicles, while critical customers notice benefits such as lighter parking efforts and variable assist levels on entry-level vehicles. Even the most critical evaluators grudgingly admit the latest and best electric systems are comparable to outgoing hydraulic systems.

With seemingly far less scrutiny, acceleration and braking functions controlled by the right foot have been negatively impacted by multiple technologies, resulting in a downward spiral of attributes noticeable to even the least critical of customers. After recently completing testing programs that included conventional and alternative fuel ultra-luxury SUVs, mid-range cars/crossovers/SUVs, and entry-level sedans, a surprising number of poorly developed acceleration and braking attributes seemed common across many of the different classes of vehicles.

The role of the 'clutch foot' may be declining in mature automotive markets, but steering feel is as important as ever

For acceleration, the basic goal is delivering the driver the acceleration (or steady-state cruise) level desired at any speed with immediate response and smooth, quick gear changes. This is a simply stated, but very difficult to achieve task. Powertrain calibrators are forced to optimize fuel economy and performance by taking a driver's input through an electronic throttle pedal, selecting a gear from a 5- to 9-speed automatic or dual-clutch transmission (or CVT) and selecting an engine power level they believe matches the gear selected and the driver's wishes. Unfortunately, the result of this is the driver's initial command has become the 'opening bid'; what and when the powertrain delivers is subject to the wishes of the calibrator. Some OEMs are able to successfully deliver acceleration attributes that are very acceptable for many different driving styles, while other OEMs simply do not develop calibrations in which the powertrain output matches the driver's command in a smooth and timely fashion.

More troubling is the shockingly poor brake pedal feel of many alternative fuel vehicles. Pedal feel, stiffness, travel/force dead bands, linearity, modulation and numerous other attributes have been compromised by the difficulty in blending the conventional brake system with the regenerative system required to improve the electric range of these vehicles. OEMs that spent years developing and then delivering exceptional brake pedal feel to the customer now offer these same customers alternative fuel vehicles with brake pedal feel which formerly would have been considered simply not acceptable for production. This is unfortunate for the customer, whose ability to confidently and consistently brake the vehicle is required to safely operate it under all driving conditions.

Let's hope the same level of scrutiny that was applied to electric power steering systems migrates to the powertrain and braking systems. Our right foot may not be as sensitive as our fingertips, but it certainly knows good from bad and there are currently a lot of bad things going on when pressing on the accelerator and brake pedals of many new vehicles.


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Topics under discussion:

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ASTON MARTIN

Second love

FOLLOWING HIS DEFECTION FROM LOTUS TO ASTON MARTIN, MATT BECKER TELLS **MARC NOORDELOOS** WHAT HE HAS PLANNED FOR THE RIDE AND HANDLING OF ASTON MARTIN'S ENTIRE RANGE OF CARS – AND ITS SUV PROJECT

Switching companies isn't usually big news in the auto industry, at least for most engineers. However, Matt Becker's move from Lotus to Aston Martin raised quite a few eyebrows, as Lotus is in the Beckers' blood. His father, Roger Becker, worked for 44 years at Lotus, including more than two decades as director of vehicle engineering, before he retired in 2010. Following in his father's footsteps, Matt Becker is another Lotus stalwart, having spent 26 years at the legendary auto maker, based in Hethel in the east of the UK. His final role was chief test and development engineer, until his January 2015 move to Aston Martin.

"I'll be very clear," says Matt Becker. "I owe everything to Lotus. Lotus got me to where I am today. Some of the people I worked with at the early stages of my career gave me the skills and the opportunity to do different projects. Like Lotus, Aston

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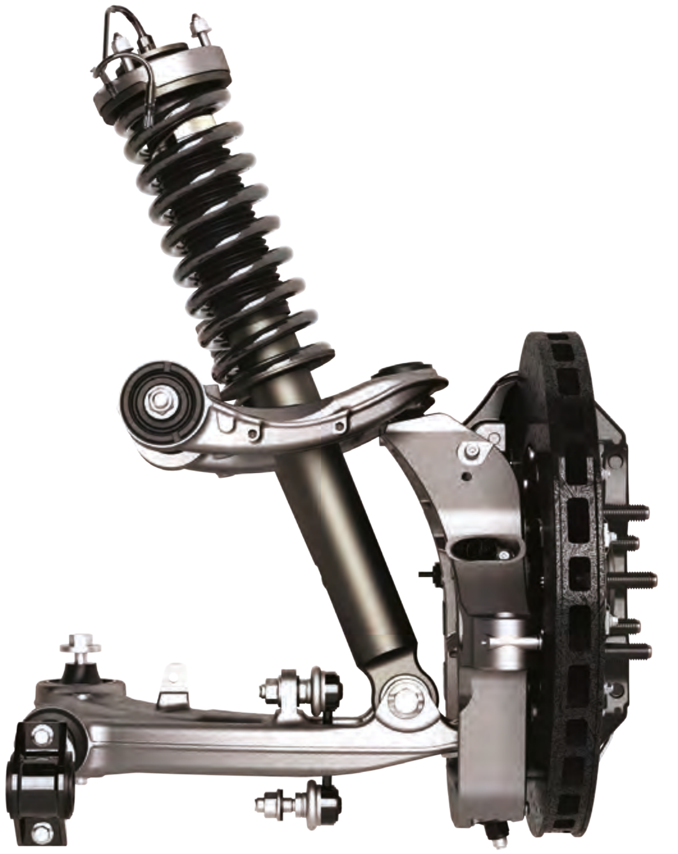


Martin is a British brand. I've always looked at Aston and admired the products: they look and sound stunning. If I think back to some of my best times at Lotus, I think back to the Evora. It started with a clean sheet of paper. The opportunity to do that again at Aston is very attractive, and I'm coming in at a great time."

Becker joins Aston Martin as chief of vehicle attribute engineering. As the company's aging VH platform prepares to exit stage left, new opportunities arise, including the DB11 (the replacement for the DB9). "It's a massive opportunity to come and look after some of the current cars – like the Vantage GT12 and hopefully a bit of Vulcan work – but also the future cars," says Becker. "There is the opportunity to work on completely new vehicles. I arrived early enough to influence the design of the DB11's suspension system."

Becker got right to work at Aston Martin, refocusing the marque's driving dynamics. "I want Astons to have a wider dynamic envelope, a bigger dynamic range of character," explains Becker. "I don't like cars that don't ride well. Ride and steering have always been my thing. Handling is incredibly important as well, but it's important to get that perfect balance between all three. That's not an easy thing to do. The Evora in many ways nailed that and that's what I want to create at Aston.

"I'm not trying to create an Evora at Aston because it's a very different company. The biggest challenge at Aston is the need to separate the models. All the future cars need to be appropriate for what they are designed to do. If it's a GT car, it needs to feel like a GT car. If it's a sportier car, then it needs to feel sportier. But they all still must have Aston DNA," he states.

Injecting that Aston DNA will be especially challenging when it comes to one particular future model, the DBX SUV, but Becker is no stranger to engineering such vehicles. "People need to remember that when I was at Lotus, I also worked for the third-party consultancy side of the business," reminds Becker. "The portfolio wasn't just mid-engine cars. I did front-engine cars. I did SUVs…"

Becker has a strong team backing him up on the ambitious Aston SUV project. "We have a very good mix of engineers at Aston," he notes. "There are half a dozen ex-Lotus people – a mixture of chassis and NVH guys – and we have quite a few Aston engineers who have been here a long time. That's good from a heritage point of view; they

"Ride and steering have always been my thing. Handling is incredibly important as well, but it's important to get that perfect balance between all three"

TOP: **THE GEN 4 DB9 FEATURES THREE-STAGE ADAPTIVE DAMPING**

ABOVE: **THE LIMITED EDITION VANTAGE V12 GT3 TAKES INFLUENCE FROM ASTON MARTIN'S GLOBAL MOTORSPORT PROGRAMS**

LEFT: **LATEST GENERATION VANQUISH UNDERGOING COLD CLIMATE TESTING**

understand the brand. There are quite a few Jaguar Land Rover (JLR) people as well, so, if you think about the knowledge they all have, that's a wide range of cars they have worked on. The team we have at Aston is in a good position to know how to develop all different types of cars."

Assisting in this growth at Aston Martin is a new technical relationship with Mercedes-Benz. The partnership was signed in December 2013 and, at this point, gives Aston access to bespoke AMG V8 engines and Mercedes electrical components. A 5% non-voting stake in the British company is the reward for Mercedes.

"It's mainly components, powertrain and electronic architecture," explains Becker. "That's the main setup at the moment. We're not working with Mercedes on any

TOP: **ASTON MARTIN HAS FACILITIES AT MIRA** (LEFT) **AND GERMANY'S NÜRBURGRING** (RIGHT)

ABOVE: **THE VULCAN IS A TRULY DRAMATIC HALO MODEL FOR ASTON MARTIN**

BELOW: **THE V12 VANTAGE IS SHOD WITH 255/35R19 PIRELLI P ZERO CORSA TIRES**

"Aston presently does only worldwide tuning. The volume of cars we make is not big enough at this moment to do a tune for this market and a different tune for that market"

dynamic aspects of the car. I haven't driven any of their cars. It's not that sort of relationship. I haven't been to Mercedes yet, although I met Tobias Moers [head of Mercedes-AMG] at Goodwood this year and we had quite a long chat."

The development of the models for this new chapter at Aston Martin takes place at a variety of locations. "One unfortunate thing at Aston is that we don't have a test track," notes Becker. "If you asked me what I miss from my time at Lotus, it's having a test track. That tool is amazingly useful."

With Aston and JLR no longer together under the Ford umbrella, Becker and his team no longer have access to the JLR test track next door to Aston in Gaydon, England. "We test at IDIADA in Spain, mostly for lane-change stability work," says Becker. "There's also Nardò, which is a fantastic test track, almost like a mini Nürburgring. We obviously use the Nürburgring quite a lot, as we have an excellent facility there. The track is very good, and you will never drive anywhere else with such high-speed cornering, but you have to be careful because you can over-compromise the car. If you tune your car strictly for the Nürburgring, then you'll compromise it for other places."

Also due to the JLR split, Aston built a new prototype and testing facility at MIRA, 32 miles from Gaydon. "MIRA allowed us to expand our prototype work to address capacity issues. We also do testing there," states Becker. "It's quite good to get the prototypes away from Gaydon, and we have a very focused team of about 20 employees at MIRA. They were able to lay out and construct the facility from scratch, exactly how they wanted it. One thing I like about Aston is that there is a consistency in corporate identity. If you go to MIRA and see the Aston Martin building, it looks special. It's the same at the Nürburgring. I'm really impressed with this company's consistency and details. It's something others should aspire to."

Like most luxury brands, Aston Martin's market is expanding strongly in China and the Middle East. These markets add new challenges for chassis tuning. "You have to go and experience the road surfaces," notes Becker. "It comes back to the third-party consultancy work I used to do at Lotus. I did a lot of work in China, so I understand the road surfaces. One of the good things that Andy Palmer [CEO] implemented when he arrived at Aston was what we call a proxy customer. For the different cars we're doing, we consider who the proxy customers are and what they would look for in that car. This allows us to look at who the customer is – to look at the musts and wants and prioritize the list. There is no point in engineers engineering cars that only engineers want – this has happened too much at other companies. If the proxy customer says that a performance feel is the most important thing they want, we can make that decision. We want to engineer cars that we can sell."

Does this mean Aston Martin will engineer the dynamics of future cars to suit certain markets? "Aston presently does only worldwide tuning," states Becker. "The volume of cars we make is not big enough at this moment to do a tune for this market and a different tune for that market. You could be clever and use a GPS sensor that recognizes where you are and tunes the suspension system to work for that region, but that's total hypothetical thinking!

"It's difficult because the American market is really into all-season tires. As a result, you lose clarity of steering. These are some of the challenges we will face, certainly with the projects coming up [DBX, etc]. That factor may drive different setups for the cars because all-season tires will be really important for the US market, but the UK is not really into all-season tires yet. We'll take that as it comes."

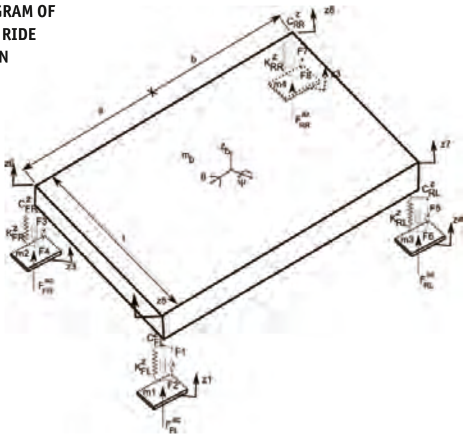
The combination of Becker's passion, as well as his skillset from the many years with Lotus, are a fantastic asset to Aston. Model expansion plans, a dynamics refocus, and a link-up with Mercedes, all indicate a fresh, bright future for the British brand.

Semi-active suspension

YASWANTH SIRAMDASU AND SAIED TAHERI FROM VIRGINIA TECH'S CENTER FOR TIRE RESEARCH HAVE DEVISED A NEW TYPE OF SEMI-ACTIVE SUSPENSION SYSTEM WITH DOUBLE DAMPERS THAT OFFERS MANY ADVANTAGES

During the 1980s the notion of replacing passive suspensions with a hydraulic-based active system was explored extensively. In 2000, Bose Corporation[1] unveiled a new active damper with electromagnetic motors claimed to respond much faster than its hydraulic-based counterpart. Looking at the practicality of implementation on production vehicles, there is an argument that there are more potential improvements with active suspension than with passive; however, in reality such highly powered systems also have several major disadvantages, including high power consumption, heavier weight, lower reliability, more complexity, much higher cost, poor noise isolation, and sensitivity to software glitches, all of which saw true active suspension shelved other than for research purposes or motorsport.

FIGURE 1: **SCHEMATIC DIAGRAM OF VEHICLE MODEL USED FOR RIDE PERFORMANCE EVALUATION**



Semi-active suspension systems, on the other hand, seem to be the best compromise in terms of cost, reliability and power consumption. These systems were originally developed by Delphi under the brand name MagneRide, for General Motors vehicles. Currently some of the premier vehicle brands use variants of these semi-active dampers. The Tenneco Acocar and H2 systems come to mind, also Bilstein Damptronic.

In this article a novel double-damper suspension is presented to show that a simple design modification can further improve the performance of semi-active suspensions. One of the objectives of this study was to create a semi-active suspension with ride performance equivalent to that of a vehicle with a fully active suspension system, without bottoming of suspension or deterioration of road-holding properties.

The single damper in a conventional suspension is proposed to be replaced with two separate dampers in parallel (Figure 1). The increased number of controllable dampers means that, during jounce or rebound, the respective damper associated with the sprung mass provides minimum damping without affecting the road-holding capability of the unsprung mass, or the unsprung mass can provide minimum damping without affecting the vibration isolation of the sprung mass. In Liu, Matsuhisa and Utsuno's paper,[2] the concept of using two controllable dampers was applied to one degree-of-freedom (1 DOF) base excitation case. It was observed that the addition of a controllable damper in parallel with a passive spring changes the equivalent stiffness of the spring, thus meaning the stiffness of the system can be controlled without physically varying the spring stiffness. With this background, two controllable semi-active dampers were used to improve the vibration characteristics of the vehicle.

Another objective of this study is to demonstrate the application of a dynamic tire model in the development of suspension ride controllers. In the past, the ride performance of a vehicle was analyzed using a simple point-contact tire model. This model is good for relatively low-frequency, transient and vertical oscillatory vehicle motions on large-wavelength road profiles where the effect of the finite length of the contact patch may be ignored.[3] This approach is not valid for ascertaining the perceived harshness rating of a suspension in response to a discrete input such as a pothole or short wavelength road profiles. In these situations, the enveloping behavior of the tire as it deforms around the road undulations is important. The longitudinal and vertical (non-linear) dynamics of the tire and suspension play a crucial role.[4]

A Lyapunov-based adaptive control algorithm was developed and used for both active and semi-active damper control. For evaluating ride comfort, the RMS (root mean square) acceleration of the vertical, roll and pitch motions on the sprung mass are used as ride performance metrics. A combination of skyhook and groundhook models are used as reference models in this research.

Both skyhook and groundhook damping concepts utilise feedback signals from the measurement of vertical and roll body accelerations to modify damper forces aimed at keeping the sprung mass (body) motionless relative to fixed lateral and longitudinal horizons.

Mathematical modeling

As this study focuses on the control of a vehicle's vertical vibration, a vehicle model is considered, with variables z_b, θ and ψ representing the vertical, roll and pitch motions of the sprung mass. The variables z1, z2, z3, and z4 represent the vertical motion of respective unsprung masses m_1, m_2, m_3, and m_4 (Figure 1). Figure 2 represents a quarter of the full vehicle considered in Figure 1. As mentioned earlier, the longitudinal force variations at the axle are caused by having uneven profiles, so an independent suspension representing compliance in longitudinal direction *X* (not shown in Figure 1) is also considered.

Figure 2 represents the active and double damper-based semi-active controllers, independently controlling the four wheels of the full vehicle as shown in Figure 1. The vertical stiffness and damping of the suspension are represented by the springs K^z_{fl}, K^z_{fr}, K^z_{rl} and K^z_{rr}, and dampers C^z_{fl}, C^z_{fr}, C^z_{rl}, and C^z_{rr}. The longitudinal stiffness and damping of the suspension are represented by the springs K^x_{fl}, K^x_{fr}, K^x_{rl}, and K^x_{rr} and dampers C^x_{fl}, C^x_{fr}, C^x_{rl}, and C^x_{rr}.

The inputs to the vehicle model are the reaction forces from the dynamic tire model at the axle and controller forces inputs F_1, F_2, F_3, F_4, F_5, F_6, F_7 and F_8, respectively. The outputs are the axle motions, which serve as inputs to the tire model. The longitudinal suspension modules at the vehicle's four wheels are independent of each other and are not controlled.

Control development

The full active and semi-active suspension controllers are developed using a quarter car model. An independent controller is fitted at each corner of the vehicle in order to minimize the vertical acceleration at each corner (z_5, z_6, z_7, z_8). In this section, all the equations are based on a representation of the front left quarter of the vehicle.

For the quarter car model with a single damper, the equations of motion of sprung (z_5) and unsprung masses (z_1) are given in state space form as:

$$\dot{Z}+\begin{bmatrix} 0 & -1 & 0 & 0 \\ \frac{K^z_{fl}}{M_s} & \frac{C^z_{fl}}{M_s} & -\frac{K^z_{fl}}{M_s} & -\frac{C^z_{fl}}{M_s} \\ 0 & 0 & 0 & -1 \\ -\frac{K^z_{fl}}{m_1} & -\frac{C^z_{fl}}{m_1} & \frac{K^z_{fl}}{m_1} & \frac{C^z_{fl}}{m_1} \end{bmatrix} Z+\begin{bmatrix} 0 \\ 0 \\ 0 \\ g-\frac{F^{az}_{fl}}{m_1} \end{bmatrix}=F$$

where $Z=[z_5\ \dot{z}_5\ z_1\ \dot{z}_1]^T$, $F=[0\ F_1\ 0\ F_2]^T$ and $M_s=\frac{m_b}{4}$.

For the quarter car model with a double damper (Figure 2), the equations of motion of the double damper constitute an additional displacement at a point in between two dampers (z_m) other than sprung (z_5) and unsprung mass (z_1).

$$\dot{z}_{m,fl}(C^z_{fl1}+C^z_{fl2})+z_{m,fl}(K^z_{fl1}+K^z_{fl2})=C^z_{fl1}\dot{z}_5+K^z_{fl1}z_5+C^z_{fl2}\dot{z}_1+K^z_{fl2}z_1$$

z_m can be solved by equating reaction forces in between parallel dampers. The equations of motion are given as:

$$\dot{Z}+\begin{bmatrix} 0 & -1 & 0 & 0 \\ \frac{K^z_{fl}}{M_s} & \frac{C^z_{fl}}{M_s} & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & \frac{K^z_{fl2}}{m_1} & \frac{C^z_{fl2}}{m_1} \end{bmatrix} Z+\begin{bmatrix} 0 \\ g-\frac{C^z_{fl1}}{M_s}\dot{z}_m-\frac{K^z_{fl1}}{M_s}z_m \\ 0 \\ g-\frac{C^z_{fl2}}{m_1}\dot{z}_m-\frac{K^z_{fl1}}{m_1}z_m-\frac{F^{az}_{fl}}{m_1} \end{bmatrix}=F$$

where C^Z_{fl1} and C^Z_{fl2} are damping coefficients of two dampers in parallel. K^Z_{fl1} and K^Z_{fl2} represent the stiffness of the upper and lower parts of the suspension spring, and here both are assumed equal to 2 K^Z_{fl} so that equivalent stiffness is the same as with the single damper model.

The skyhook-groundhook reference model

A 2DOF skyhook and groundhook reference model (Figure 3) is used to obtain the desired position and velocities for the control algorithm to follow. C_{sky} and C_G are selected appropriately to guarantee fewer vibrations of the sprung mass and less hopping of the unsprung mass. Note that these values should be based around actual controlling suspension parameters so that the desired values are within physical limits. The equations of motion of desired sprung and unsprung mass are given by:

$$\dot{Z}^d+\begin{bmatrix} 0 & -1 & 0 & 0 \\ \frac{K^z_{fl}}{M_s} & \frac{C_{sky}}{M_s} & -\frac{K^z_{fl}}{M_s} & 0 \\ 0 & 0 & 0 & -1 \\ -\frac{K^z_{fl}}{m_1} & 0 & \frac{K^z_{fl}}{m_1} & \frac{C_G}{m_1} \end{bmatrix} Z^d+\begin{bmatrix} 0 \\ 0 \\ 0 \\ g-\frac{F^{az}_{fl}}{m_1} \end{bmatrix}=0$$

From the above equations, the motion of sprung mass is not affected by the groundhook damper, and unsprung mass is not affected by the skyhook damper due to the attachment of each damper to an inertial reference frame. This is the main reason for using skyhook-groundhook as an optimal control policy.

Control algorithm

A new Lyapunov-based adaptive control algorithm has been developed for ride control. The algorithm consists of a proportional feedback part and a full dynamic feed-forward part which estimates unknown model parameters online. Due to its simplicity and fast response, it is

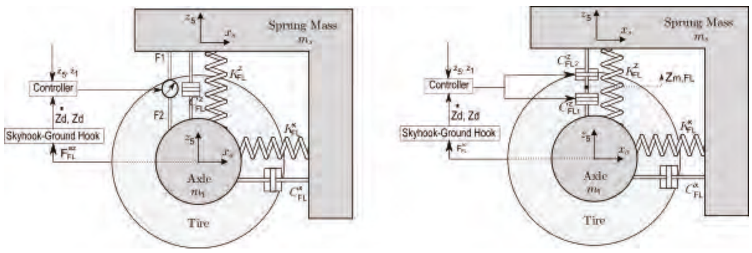


FIGURE 2: **FULL ACTIVE CONTROLLER AND DOUBLE DAMPER-BASED SEMI-ACTIVE CONTROLLER AT FRONT LEFT SIDE OF VEHICLE**

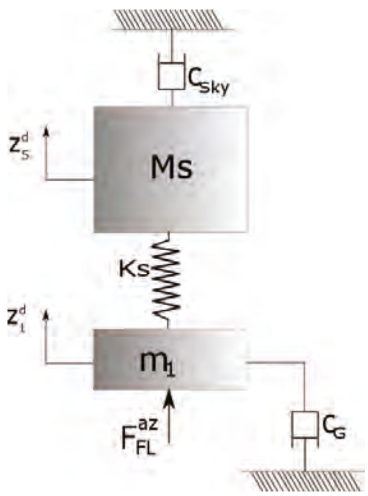


FIGURE 3: **SCHEMATIC DIAGRAM OF SKYHOOK-GROUNDHOOK REFERENCE MODEL**

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suitable for practical implementation on a full vehicle model.

The method requires the equations of motion of the dynamic system under consideration to be of the form

$$\mathbf{A}\dot{Z} + \mathbf{B}Z + C = F$$

In the above form, F is the control force output from the control algorithm.

To derive the control algorithm and adaption law, a Lyapunov function is considered.

$$V(Z,t) = \frac{1}{2}(\tilde{Z}^T \mathbf{A}\dot{\tilde{Z}} + \tilde{p}^T \Gamma \tilde{p}) + \int \tilde{Z}^T \mathbf{B}\tilde{Z}\, dt$$

where p is an n-dimensional vector containing n unknown model parameters and $\tilde{Z} = Z - Z^d$ is the error in states and $p = p - p$ is the parameter error between the estimated p and nominal parameters p. The Lyapunov function is always positive definite if the gain matrix is Γ positive definite. Here it is selected as positive diagonal matrix. If the derivative of $V(Z, t)$ is negative definite, then the system is asymptotically stable. Differentiating $V(Z, t)$ yields

$$\dot{V}(Z,t) = Z^T[-\mathbf{B}Z^d - C + F - \mathbf{A}\dot{Z}^d] + \tilde{p}^T \Gamma \dot{\tilde{p}}$$

The control law, as mentioned earlier, consists of a feedback part and a full dynamics feed-forward part and is defined as

$$F = \hat{\mathbf{A}}\dot{Z}_d + \hat{\mathbf{B}}Z_d + \hat{C} - K_p\tilde{Z}$$

where Kp is positive definite proportional gain matrix and let $\tilde{A} = \hat{A} - A, B = B, C = C - C$ represent error between estimated ($\hat{A}$, B and C) and nominal model parameters. The control law in Equation 6 is globally asymptotically stable such that

$$\dot{V}(Z,t) = -\tilde{Z}^T K_p \tilde{Z} \leq 0$$

For detailed derivation and implementation of control law to single damper- and double damper-based suspension controllers, refer to Siramdasu.[5]

As the suspension is semi active, these control forces have to satisfy two criteria: one is the minimum F_{min} and maximum forces F_{max} generated by the dampers; and the other is the input without energy, i.e a force in the direction of motion of the mass is not applied, and a damper can only oppose the motion of the mass.

The control forces are constrained, using simple *if* logic, in between F_{min} and F_{max}, based on the physical limitations of the damper.

$$F_{i,min} \leq F_i \leq F_{i,max}, \quad i = 1, 2$$

$$F_{1,min} = C_{fl1,min}(\dot{z}_5 - \dot{z}_{m,fl})\dot{p}_1, F_{1,max} = C_{fl1,max}(\dot{z}_5 - \dot{z}_{m,fl})\dot{p}_1,$$
$$F_{2,min} = C_{fl2,min}(\dot{z}_{m,fl} - \dot{z}_1)\dot{p}_2, F_{2,max} = C_{fl2,max}(\dot{z}_{m,fl} - \dot{z}_1)\dot{p}_2$$

where $C_{fl1,max}$ and $C_{fl1,min}$ are maximum and minimum allowable damping by the upper damper. $C_{fl2,max}$ and $C_{fl2,min}$ are the maximum and minimum damping allowable by the lower damper. Note that the values of C_{fl1} and C_{fl2} have to be non-zero; if not, the open-loop system will have poles at the limit of stability and the discretized state space model can become unstable. Therefore, non-zero positive nominal values have been considered. At any time, the total maximum and minimum damping available are $C_{fl\,i,max} + C_{fl\,i}$ and $C_{fl\,i,min} + C_{fl\,i}$, respectively.

After satisfying the constraints in Equation 10, for restricting the forces such that no energy is introduced into the damper, the following clipping method is used, such that if the control force F_1 or F_2 and relative deflection velocity ($\check{z}_5 - \check{z}_{m,f,l}$) or ($\check{z}_{m,f,l} - \check{z}_1$) are of same sign then the control applies the minimum

$$F_1 = \begin{cases} F_1 & \text{if } (\dot{z}_5 - \dot{z}_{m,fl})F_1 \leq 0 \\ F_{1,min} & \text{if } (\dot{z}_5 - \dot{z}_{m,fl})F_1 > 0 \end{cases}$$

$$F_2 = \begin{cases} F_2 & \text{if } (\dot{z}_{m,fl} - \dot{z}_1)F_2 \leq 0 \\ F_{2,min} & \text{if } (\dot{z}_{m,fl} - \dot{z}_1)F_2 > 0 \end{cases}$$

Simulation

The values used for the simulation are M_s = 300Kg, m_1= 42.27Kg, K^z_{fl} = 2000N/m, $K_1 = K_2 = 2\ K^z_{fl}$, C^z_{fl} = 2,000 N/m/s, C^z_{fl1} = 100N/m/s, C^z_{fl2} = 50N/m/s, $C_{fl1,max}$ = 6,500N/m/s, $C_{f2l,max}$ = 3,500N/m/s, $C_{fl1,min}$, $C_{fl2,min}$ = 0N/m/s, C_{sky} = 2,000N/m/s, C_G = 1,550N/m/s. The adaptive gain matrix Γ = diag [8×10^{11} 8×10^{11}] and propositional gain matrix K_p = diag [1 1 1 1]. The initial vertical deflection values (z_5, z_1) are assumed to be equal to initial axle deflection z_a. Initial velocities ($\check{z}_5$, $\check{z}_1$) are assumed to be zero.

From the formulations of the control algorithm, the computed control forces are applied to the equations of motion for the single and double dampers, based on the full vehicle model (Figure 1). The input road profile used in this study is shown in Figure 4. The road profile is of asphalt concrete and it represents a measured section of smart road at the Virginia Tech Transportation Institute, with a longitudinal road resolution of 1cm.

Figure 4 shows the road profile on the left and right sides of the vehicle. An artificially created 1cm cleat is added to the measured road data at a longitudinal distance of 85m, to evaluate the harshness mitigation of the ride controller. Figure 4 also represents the elevation power spectral densities of the left and right road profiles. The road profiles considered are short-wavelength road profiles (Figure 4), with more frequency content in the power spectral densities between the wavelengths of 0.1m/cycle and 0.5m/cycle (or between wave numbers of 2 cycle/m and 10 cycle/m). The abrupt peak at a wave number of 2 cycle/m is due to the cleat in the road profile.

From the previous study[4], it is observed that the dynamic response of the tire as it deforms around the road input can excite both the longitudinal and vertical dynamics of the tire and suspension. These dynamic changes in the contact patch and the enveloping of low-amplitude sharp elevation changes are considered in this study using a rigid ring-based tire model[4], which is valid up to at least 75Hz. Figure 5 shows the developed simulation tool with a flowchart of inputs and outputs from vehicle, tire and suspension control modules.

For characterizing the ride performance, a simple criteria of RMS

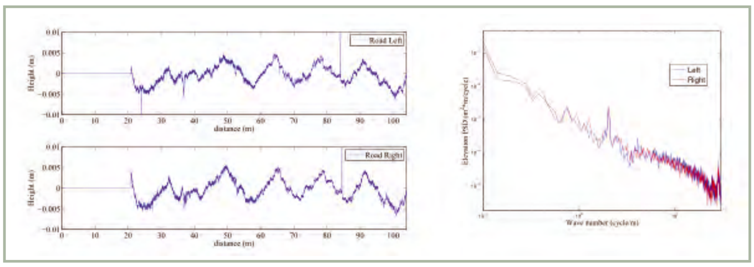

FIGURE 4: **MEASURED ROAD PROFILE AND POWER SPECTRAL DENSITIES ON LEFT AND RIGHT SIDE OF VEHICLE**

acceleration of sprung mass vertical, pitch and roll motions at CG are considered. The road-holding properties are characterized by maximum axle or unsprung mass displacement z_1. The suspension bottoming is characterized by suspension deflection (z_5, z_1). The simulations of no control, active-controlled single damper and semi-active controlled double damper are then performed. The respective RMS accelerations of the sprung system at different speeds, using the input road profile in Figure 4 are computed and summarized in Tables 1, 2 and 3. The maximum tire deflection and suspension deflection values are also computed at all four wheels, as shown in Tables 4 and 5. For all three cases, no such abnormal behavior of controlled suspensions from normal suspension is observed.

From Tables 1, 2 and 3 it can be seen that the RMS accelerations of active and semi-active suspensions are low compared to the no control case. As mentioned earlier, due to the use of the double damper-based suspension control, the damping constants of the two dampers are controlled independently, which gives the advantage of increasing the performance of the semi-active controller, which is very clearly evident at all speeds. The RMS acceleration values of the fully active case are almost equal to the semi active case at all the speeds. The roll RMS acceleration for the semi-active double damper suspension is a little higher than in the active case. This is because the controllers at the four wheels are indirectly minimizing the roll acceleration of the sprung mass by independently optimizing the RMS accelerations at the respective wheels.

It is observed that at a lower velocity of 15km/h, respective RMS acceleration values are almost the same in all three cases, due to the enveloping characteristics of tires, which damp most of the road vibrations. Table 4 shows the maximum suspension deflection values and Table 5 shows the maximum tire deflection for all the three cases. Although these values increase in the case of active control, they are within the acceptable range, with maximum suspension deflection of 3.5cm and maximum axle deflection of 3.3cm.

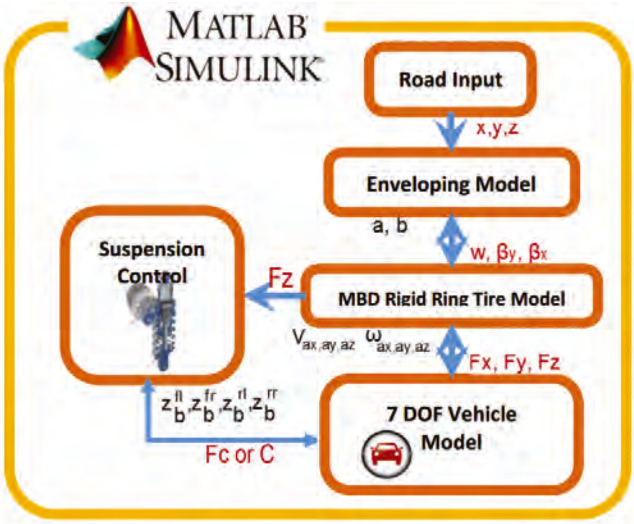

FIGURE 5: **SCHEMATIC OF SUSPENSION CONTROLLER WITH INPUT AND OUTPUTS**

Figure 6 shows the vertical, pitch and roll acceleration of the sprung mass at vehicle velocity of 75kph. The most important outcome is the equivalent ride performance in both control cases. Thus semi-active based double-damper suspension can emulate the active suspension. When the front and rear axles of the vehicle roll over the cleat, oscillations in no control case can

Velocity (km/h)	15	30	45	60	75
No Control	0.0796	0.1136	0.1411	0.2001	0.2605
Full Active	0.0601	0.0603	0.0888	0.1344	0.1627
Semi Active	0.0615	0.0636	0.0911	0.1405	0.1753

TABLE 1: **RMS VERTICAL ACCELERATION OF SPRUNG MASS (M²/S) AT DIFFERENT VELOCITIES (KM/H)**

Velocity (km/h)	15	30	45	60	75
No Control	0.0554	0.0857	0.1	0.1255	0.1483
Full Active	0.0019	0.0458	0.0602	0.0737	0.0869
Semi Active	0.0021	0.0479	0.0607	0.0782	0.0897

TABLE 2: **RMS PITCH ACCELERATION OF SPRUNG MASS (RAD²/S) AT DIFFERENT VELOCITIES (KM/H)**

Velocity (km/h)	15	30	45	60	75
No Control	0.1671	0.2555	0.316	0.3302	0.3416
Full Active	0.112	0.0811	0.091	0.0925	0.09
Semi Active	0.1206	0.0986	0.1165	0.13	0.1356

TABLE 3: **RMS ROLL ACCELERATION OF SPRUNG MASS (RAD²/S) AT DIFFERENT VELOCITIES (KM/H)**

Velocity (km/h)	15	30	45	60	75
No Control	2.67	2.71	2.71	2.79	2.77
Full Active	3.01	3.12	3.18	3.5	3.5
Semi Active	2.75	2.69	2.69	2.88	2.79

TABLE 4: **MAXIMUM SUSPENSION DEFLECTION (CM) AT DIFFERENT VELOCITIES (KM/H)**

Velocity (km/h)	15	30	45	60	75
No Control	2.61	2.51	2.55	2.58	2.6
Full Active	3.03	3.08	3.1	3.14	3.3
Semi Active	2.7	2.51	2.56	2.57	2.57

TABLE 5: **MAXIMUM AXLE DEFLECTION (CM) AT DIFFERENT VELOCITIES (KM/H)**

be observed. In both control cases, the controller is effectively dampening these oscillations in the vertical, pitch and roll directions.

Figure 7 shows the two semi active dampers for each of the front wheels of the vehicle. It is observed that the upper damper values C_{fl1} and C_{fr1}, which are attached to the sprung mass, can control low-frequency body vibrations. The lower damper values C_{fl2} and C_{fr2}, which are attached to the unsprung mass, vary randomly, thus controlling most of the random vibrations from road undulations.

This finding effectively validates that the double-damper-based semi-active suspension can independently control usprung and sprung masses, thus emulating as close to an active suspension as possible. All the upper dampers are within the saturation limit of $C_{fl1,max}$ = 6,500 and lower dampers are within the saturation limit of $C_{fl2,max}$ = 3,500, as imposed on each damper in Equation 10. Figure 8 show the dissipative constraint on the semi-active dampers based on damper velocity as defined in Equation 11.

$F_{Up,max}$ and $F_{Up,min}$ correspond to maximum and minimum constrained forces on upper dampers and $F_{Low,max}$ and $F_{low,min}$ correspond to maximum and minimum constrained forces on the lower dampers. It is also evident that unsprung mass experiences more vertical deflection velocity than sprung mass, and thus more vibrations are dampened by the lower damper. The saturation limit on the upper damper is greater than that of the lower damper, which is also evident from the slope of $F_{low,min}$ being greater than the $F_{Low,max}$.

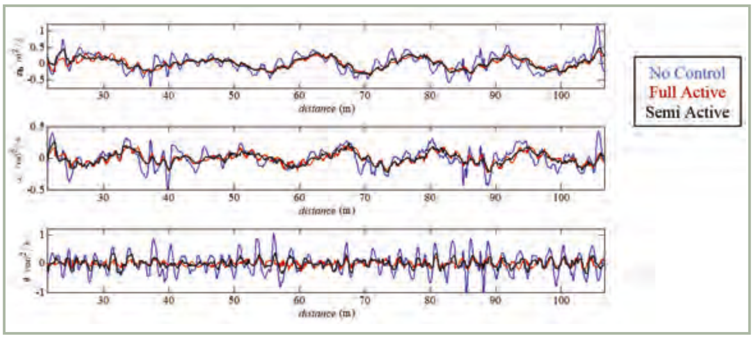

FIGURE 6: **RMS ACCELERATION OF SPRUNG MASS AT 75KM/H WITH NO CONTROL, ACTIVE AND SEMI-ACTIVE CONTROL**

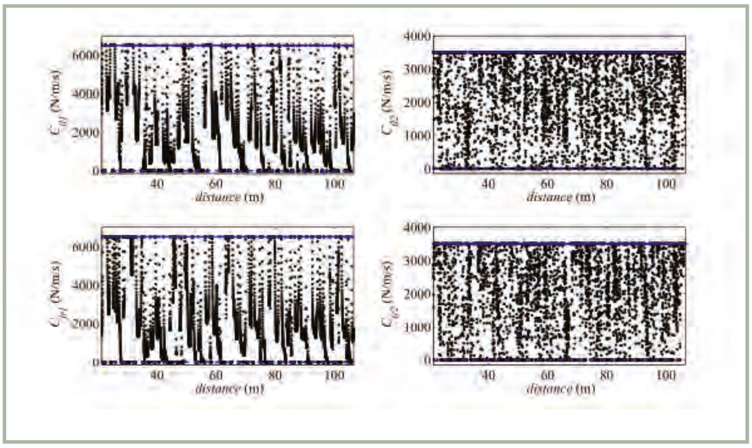

FIGURE 7: **DAMPING COEFFICIENTS OF BOTH FRONT DAMPERS WITHIN MAXIMUM AND MINIMUM LIMIT OF THE DAMPER AT 75KM/H**

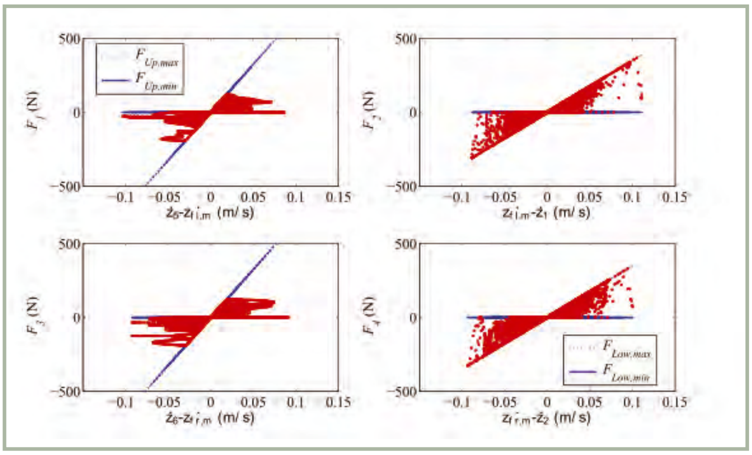

FIGURE 8: **DISSIPATIVE DOMAIN OF FRONT SEMI-ACTIVE DAMPERS**

Conclusion

The designed controller is used for the full active control of single-damper suspension and semi-active control of a double-damper suspension. The ride performance was evaluated under short-wavelength road profiles and a road profile with cleats. The simulation results demonstrated that the novel semi-active suspension system can emulate an active suspension without bottoming of the suspension or deterioration of road-holding properties. Semi-active suspension results are shown to be constrained by the saturation and energy limitation of the damper.

This approach of ride control based on double dampers can be substituted for full active suspension and is shown to significantly improve the ride performance of a vehicle, as well as reducing power consumption, cost and complexity, and increasing reliability compared with a full active suspension system.

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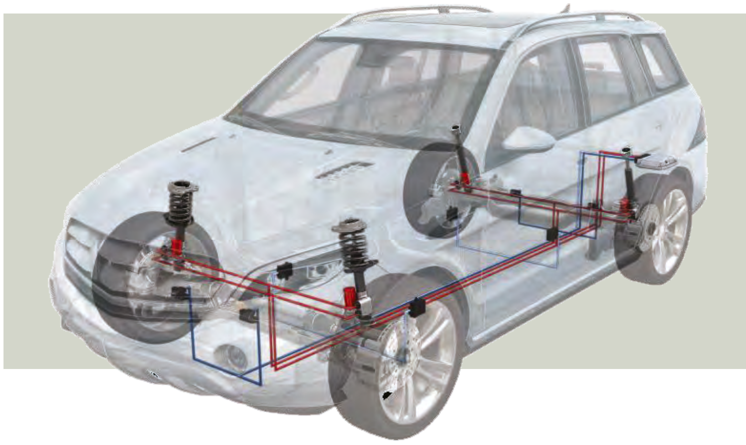
Intelligent suspensions

ESTEBAN MÉNDEZ AND GUNTHER BISMANS, BOTH TECHNICAL EXPERTS AT TENNECO, EXPLAIN THE MARKET AND TECHNOLOGY OF INTELLIGENT SUSPENSION SYSTEMS

RIGHT: **CVSA2 IS BEING ENGINEERED FOR APPLICATION IN AN SUV**
BELOW: **ILLUSTRATION OF A CVSA2 ACTUATOR**



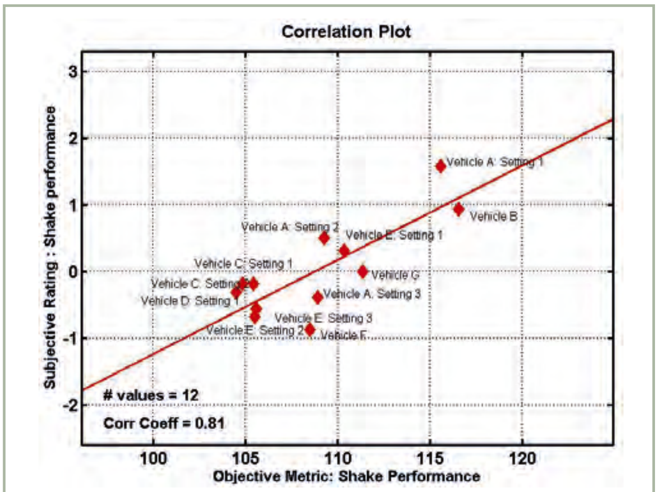
To fulfill customer needs for a more comfortable and enjoyable ride, OEMs can offer electronically controlled suspension systems instead of the conventional passive systems.

These electronically controlled suspension systems, or intelligent suspension systems, allow the driver to control the ride mode to make the drive more comfortable or more sporty, according to the driver's individual taste. Using various sensors to detect road conditions and driving situations, the suspension adjusts itself continuously in real time to maximize both driving comfort and handling performance. This state-of-the-art technology offers the potential to enhance the ride experience compared with conventional dampers, which only have one damper setting and are therefore always a compromise between comfort and control. In order to offer drivers more options, these intelligent suspension systems closely cooperate with other vehicle systems, such as the engine, the automatic transmission, and the power steering systems.

Consumers and professionals say

An independent consumer clinic involving a test group of 150 people demonstrated that more than 80% of consumers in different vehicle segments (compact class, upper mid-range and SUV) value intelligent suspension systems over conventional systems and are even willing to pay a fair option price for them. In road tests performed by an independent testing institute, drivers rated intelligent systems highly because of the improved wheel-to-road contact on wet and broken road surfaces, improved stability during lane changes, and strongly reduced oscillations during obstacle avoidance maneuvers. During a double-lane change test with a compact car, steering angle correction was reduced by 15% and the side-slip angle was reduced by 37%.

BELOW: **FIGURE 1, CORRELATION PLOT BETWEEN OBJECTIVE AND SUBJECTIVE SHAKE PERFORMANCES**



Dual-valve semi-active suspension

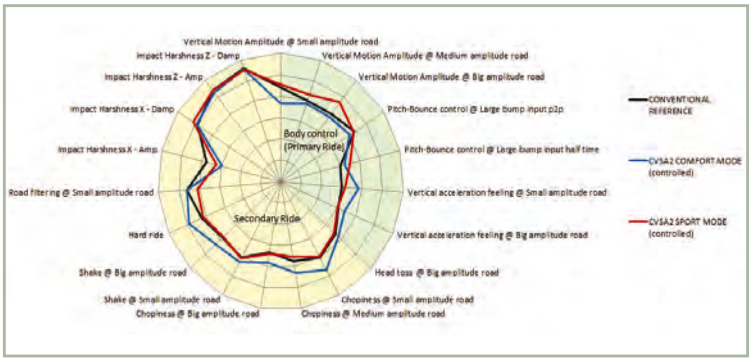
There are different types of electronic suspension systems available and each type is tailored for a specific car segment. Selective dampers for sportier compact cars enable the driver to manually choose between a comfortable damper setting for daily traffic and a sport mode for a more dynamic experience. For the larger car segment, single-valve or dual-valve semi-active suspensions are available where the dampers are continuously adjusted by an onboard computer. Compared with single-valve solutions, two-valve systems offer more room for both comfort and vehicle handling, and they can also generate the higher damping forces that are needed for heavier vehicles and more extreme sport behavior. In this article, we will focus on the two-valve technology with Tenneco's latest development, CVSA2.

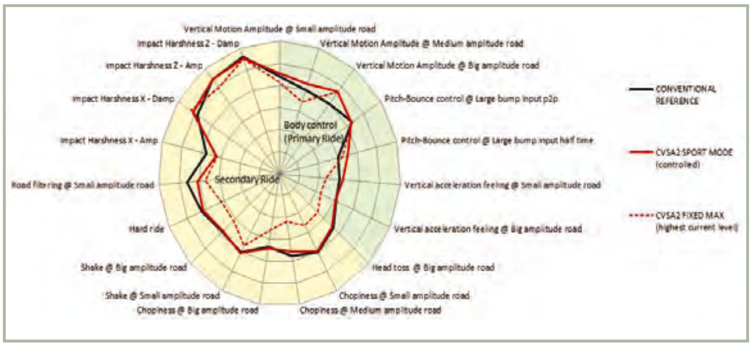
The vehicle system consists of four electronically controlled shock absorbers that are connected to a central electronic control unit (ECU). The shock absorbers have two electronic servo valves to control the damping, and each valve can be independently tuned on both compression and rebound damping characteristics.

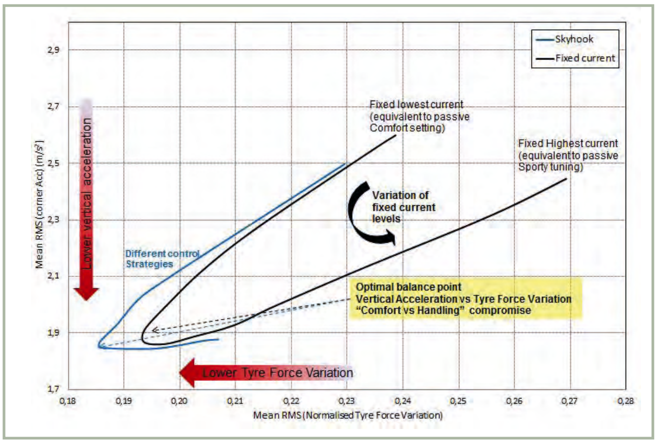
Tenneco has designed its two-valve CVSA2 actuator around a lightweight aluminum monotube damper. The mono tube concept further reduces the weight of the damper and allows for the unit to be mounted upside down when necessary, for packaging reasons or for unsprung weight reduction. Although many components are mounted externally, the design of the valve block can be flexibly tailored to meet packaging requirements for different suspension configurations. NVH performance has also been improved with the monotube design compared with a twin-tube design.

While the vehicle is being driven, the ECU collects data from several accelerometers mounted on the vehicle body, which provide information related to body modes such as roll, pitch and heave. Accelerometers on the unsprung mass provide information about suspension motion, which allows accurate wheel control under all driving situations.

Furthermore, the controller area network (CANbus) provides the ECU with data about the vehicle's speed, steering inputs and brake applications. The control algorithm in the ECU uses all the input data and the driver selected ride mode







ABOVE: **FIGURE 2, GRAPH SHOWS VERTICAL ACCELERATION VERSUS TIRE FORCE VARIATION**
LEFT UPPER: **FIGURE 3, COMPARISON BETWEEN STANDARD, SPORT AND COMFORT MODES**
LEFT LOWER: **FIGURE 4, COMPARISON OF STANDARD (CONVENTIONAL) VERSUS CONTROLLED AND FIXED CURRENT MODES**

(typically 'comfort', 'neutral/normal', and 'sport') to calculate the best damper settings in each situation in real time via electrical current sent to the electronic valves.

Monroe CVSA2 intelligent suspension system performance

To better understand the role of shock absorbers in vehicle performance, Tenneco developed an objective ride comfort characterization in two identical E-segment vehicles. One of the vehicles was equipped with passive conventional production dampers, and the other with Tenneco's CVSA2 semi-active dampers.

The vehicles were fitted with accelerometers on the unsprung mass, sprung mass and driver's seat. This setup was designed to capture the complete transfer path, from the road input to the driver.

For the ride comfort characterization exercise, extensive tests were performed using different roads and vehicle speeds to study performance in the whole range of frequencies that define ride comfort.

To showcase the advantages that the real-time control of the CVSA2 two-valve semi-active suspension system brings in terms of vehicle performance, the tests were carried out in both controlled modes and fixed currents.

To graphically quantify the improvements in performance, the radar plots in Figures 1 and 2 have been normalized using previously established subjective-to-objective correlation data.

Comparing the reference conventional dampers and the two different controlled modes – 'comfort' to give a relaxed feel to the vehicle and 'sport' to provide a more extreme driving experience – in the CVSA2 system, the improvement in the secondary ride when in 'comfort' mode can be seen through the more 'floating' or 'fluid' behavior, which helps give a feeling of comfort. The 'sport' mode shows similar secondary ride performance to the conventional damper and an improvement in body control.

To further illustrate the advantages of a semi-active system, Figure 1 shows a comparison between the vertical acceleration level in the sprung mass (in one corner) and the tire force variation.

The data shown is derived from four-poster testing, comparing fixed current modes from the lowest to the highest damping force, simulating different passive tuning philosophies (black line) and different tuning parameters of the controller (blue line) by adjusting the gains and current commands on the control algorithm.

The optimal point in a passive suspension depends on the trade-off between comfort and handling that is adopted during the tuning process. With a semi-active system, a better compromise between comfort and handling can be achieved (indicated by the blue line in the chart).

The effect of the control strategy in the vehicle level can also be illustrated with a spider chart (Figure 4), which compares the skyhook strategy and the maximum fixed current (which creates the highest damping force level). From this chart, it can be seen that the degradation of the secondary ride required for a good level of body control in the fixed current mode is not observed in the 'sport' dynamic mode.

Conclusions

Dual-valve technology brings a noticeable improvement to vehicles compared with a conventional suspension with respect to both ride comfort and vehicle handling.

An increasing number of customers appreciate this added value, and several OEMs now offer such systems as standard on premium vehicles.

Tenneco's CVSA2 combines the semi-active two-valve technology with an optimized lightweight mono tube design, which offers superior NVH characteristics and dynamic performance. The CVSA2 technology is currently applied on sports cars and is currently being engineered for production on an SUV. Tenneco has done extensive work to relate subjective and objective validation with the ultimate goal of using this validation as an efficient tool in the design process of the entire suspension system, including the dampers, components and control system, to deliver optimum performance at an affordable cost.

Smart steering

INTELLIGENT HYDRAULIC STEERING ASSIST OPTIMIZES STEERING PERFORMANCE IN ALL COMMERCIAL VEHICLE SEGMENTS

Trucks and buses could soon be driving autonomously with the help of iHSA (intelligent Hydraulic Steering Assist). tedrive Steering Systems of Wülfrath, Germany, has developed a system that, as an interface to all driver-assistance systems, supports active safety and comfort functions as we head toward autonomous driving. Indeed tedrive's recirculating ball steering systems can now serve as an interface to driver assistance systems, with iHSA helping commercial vehicle manufacturers in their efforts to make automated driving fit for the future with hydraulic steering systems.

The precursors to this type of technology, among them active lane-keeping assistance, cross-wind compensation, parking assistance, city mode, and automated approach to access ramps, are examples of the functions that can be realized through use of iHSA. They provide active and direct support that takes the load off the driver.

The tedrive iHSA module permits all regular driver assistance systems to be connected to the hydraulic steering system. This means driver assistance systems that were previously reserved for vehicles with electric steering systems can now also be made available for vehicles with high axle loads.

The vehicle must be equipped with the necessary sensors for recognizing its surroundings, and in the event the vehicle leaves the defined lane, the sensors send a correction signal to the iHSA module, which automatically controls the steering system's hydraulic valve to correct the vehicle trajectory – if necessary, without any driver input. The functionality extends well beyond the lane departure warning systems already required by law.

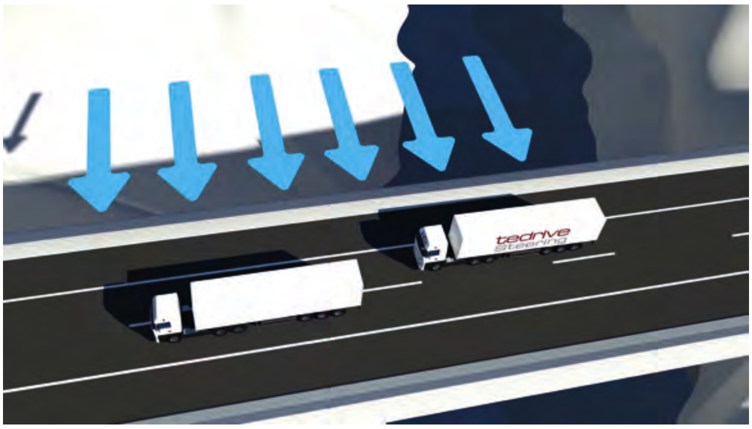
It is in heavy commercial vehicle traffic and public transport in particular that autonomous driving promises a considerable improvement in accident prevention and the reduction of serious accidents. The technical principle of iHSA allows all relevant driver assistance systems to be coupled to tedrive's hydraulic steering system. In combination with front and side radar sensors, such as those used for adaptive cruise control, active braking and active lane keeping, iHSA supports major functional elements of automated driving. The iHSA module combines the benefits familiar from electric power steering systems with those of conventional hydraulic steering units, while retaining a robust overall design suitable for use in cars, light trucks, heavy commercial vehicles, buses and special vehicles with high front-axle loads.

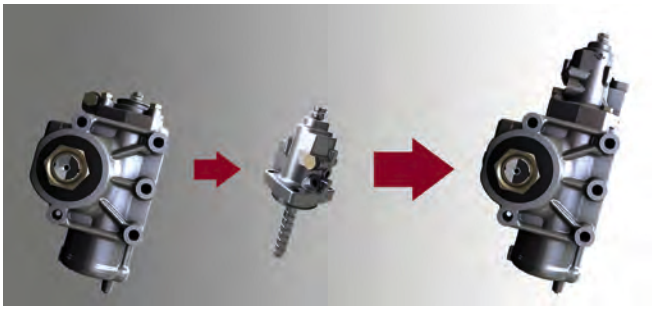
What is the iHSA technology?

The iHSA technology can be used modularly in combination with hydraulic tedrive recirculating ball steering, as well as with tedrive rack-and-pinion systems. The power assistance in these systems is provided by the integrated hydraulic cylinder, with a hydraulic valve controlling the level of assistance.

In conventional steering systems, the steering input from the driver regulates the hydraulic assistance, which is implemented by the hydraulic valve diverting the hydraulic fluid into the respective

RIGHT: **PROVEN TEDRIVE RECIRCULATING BALL STEERING GEAR TECHNOLOGY COMBINED WITH THE IHSA MODULE NOW ALSO ENABLES THE USE OF ACTIVE DRIVER ASSISTANCE SYSTEMS AND MANY MORE SAFETY AND COMFORT FUNCTIONS IN BUSES**





cylinder chamber. The iHSA system uses the available hydraulic valve, but controls it independently of the driver via a compact electric motor. The motor can be very small, as it does not deliver any actual steering assistance, serving only to control the hydraulic valve. The motor's power requirement is therefore very low, which protects the on-board electric system and does not necessitate any changes to energy management and vehicle electrics.

Installed alongside the motor is a torque sensor that measures the driver's steering movements, providing the data necessary for system regulation. A control unit gathers all the signals and contains the algorithms required for controlling the steering. The system provides the interface to the vehicle communication system, such as the CANbus, and facilitates the application of hydraulic power steering in conjunction with assistance systems. This torque overlay provided by the iHSA module means, for instance, that trucks and buses can be actively kept in the correct lane without the need for driver intervention. This functionality goes well beyond the currently legislated lane-keeping warning systems. Furthermore, the plug-in module enables the incorporation of functions such as automatic cross-wind compensation, trailer stabilization, city mode, nibble control and joystick maneuvering assistance. For buses, it also facilitates an automated approach to bus stops and boarding points.

Using an additional on-demand hydraulic pump with the iHSA steering system allows for adjustment of the volumetric flow within the system. If there is no demand for power assistance, the volumetric flow drops, along with frictional losses. The use of iHSA technology means that volumetric flow can also be maintained at a low, CO_2-optimized level for small steering inputs.

Active steering

The development of the tedrive iHSA module has succeeded in transforming hydraulic steering into an active steering system.

The development of the iHSA module significantly expands the performance parameters of hydraulic steering systems, successfully transforming them into active steering systems incorporating all the functions of electromechanical power steering. The active hydraulic solution is variable and independent of front axle load. Alongside improved steering functionalities, the plus points include optimized packaging dimensions, cost and design benefits for platform strategies, and optimized potential for CO_2 savings.

To guarantee functional safety, the tedrive iHSA system is developed in accordance with ISO 26262. According to the company, in a comparison between iHSA steering and an electric power steering (EPS) system, the iHSA system demonstrated a lower level of risk in terms of functional safety (ASIL B/C). This is based on the fact that the maximum applied torque overlay is mechanically limited and is considerably lower than that of EPS. Thus, even in the event of a system malfunction, the driver is always able to override it, choosing instead to steer the vehicle him/herself.

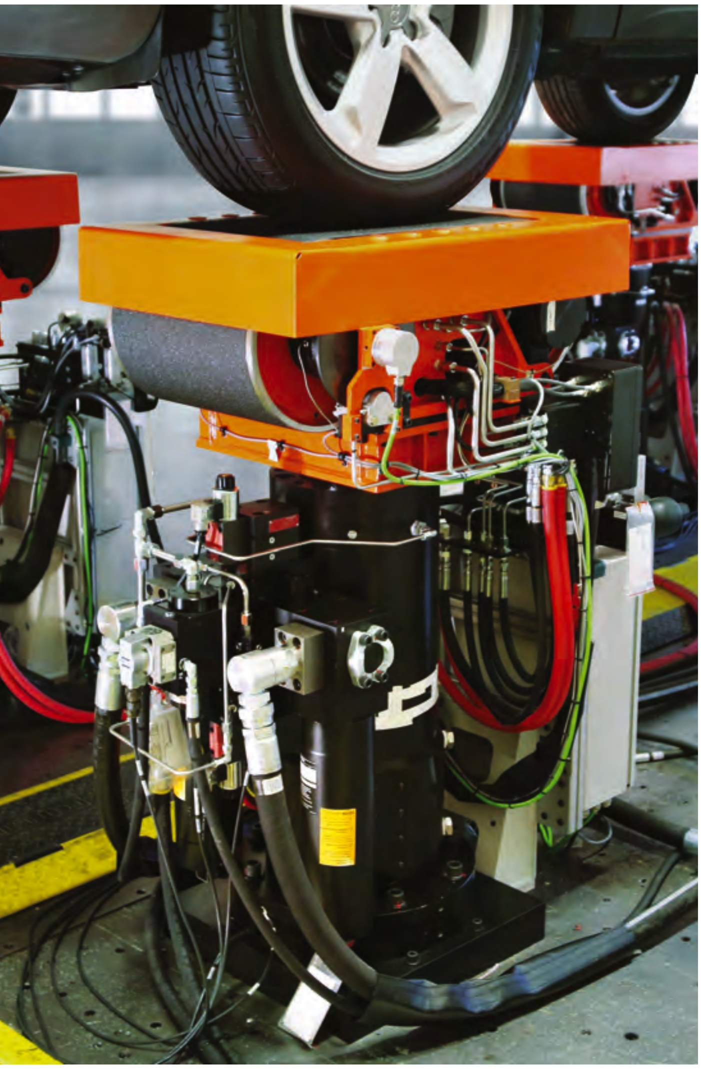
TOP LEFT: **ON APPROACHING A BUS STOP RAMP, THE TEDRIVE SYSTEM STEERS THE BUS TO THE CURB AT A PRE-DETERMINED DISTANCE, REDUCING TIRE WEAR**
TOP RIGHT: **TEDRIVE INCREASES SAFETY AND STEERING COMFORT FOR TRUCK DRIVERS WITH PERFORMANCE-ENHANCED RACK-AND-PINION STEERING**
ABOVE LEFT: **THE IHSA MODULE SUPPORTS THE INCORPORATION OF ALL CURRENT DRIVER ASSISTANCE SYSTEMS SUCH AS AUTOMATIC CROSSWIND COMPENSATION**
ABOVE RIGHT: **DRIVER ASSISTANCE SYSTEMS FAMILIAR FROM THE CAR SECTOR CAN BE IMPLEMENTED IN TRUCKS AND BUSES NOW**

High-fidelity testing

MTS's FLAT-TRAC RIDE COMFORT ROADWAY IS AN EASY WAY TO BRING HIGH-FIDELITY TESTING INTO THE TEST LAB

To help automobile manufacturers better address growing industry requirements for more demanding ride comfort evaluation, MTS is expanding its range of flat-belt roadways to include the new Flat-Trac Ride Comfort Roadway.

Today's emphasis on ride comfort is driven by several factors. The global focus on increased fuel efficiency and reduced emissions has led to quieter cabins, making noise and vibration much more noticeable to passengers. The increasing adoption of active and semi-active suspensions has made vehicle benchmarking and tuning more complex and time intensive. Also, an industry-wide trend toward platform consolidation means that each vehicle platform must be specifically tuned and optimized for many individual regional markets.



BELOW AND MAIN: **MTS's FLAT-TRAC RIDE COMFORT ROADWAY COMBINES A ROBUST FOUR-POST SYSTEM WITH MOVING BELTS FOR PERFORMING RIDE COMFORT EVALUATION, BENCHMARKING AND TUNING**

Conventional approaches to ride comfort evaluation are proving less than ideal for meeting these evolving demands. The proving ground approach is expensive, time consuming, not repeatable and requires access to prototypes, which are in increasingly short supply. Lab-based four posters, while more affordable and repeatable, lack spinning tires and therefore offer a low degree of accuracy for ride comfort testing. Lab-based dynamic roadways, while repeatable and fully equipped to address new demands, represent major investments in facilities and capital. What has been missing is a ride comfort solution that achieves a more practical balance of functionality and affordability.

To fill this void, MTS has developed the Flat-Trac Ride Comfort Roadway – a lab-based, four-post system with moving belts at each vehicle corner that provides far more realistic simulation than conventional four posters and represents an affordable alternative to full-featured dynamic roadways and proving ground testing.

With this new roadway system, test engineers gain an accurate

LEFT: **LAB-BASED TUNING OF ACTIVE AND SEMI-ACTIVE SUSPENSIONS IS POSSIBLE, THANKS TO THE MOVING TIRES PROVIDING REAL VEHICLE FEEDBACK TO ECUs**

and repeatable means of performing directly observable full-vehicle vibration analysis, benchmarking, suspension tuning and validation. Engineered to deliver high-fidelity ride comfort simulation, it enables fast and efficient acquisition of meaningful component, subsystem and full-vehicle performance data earlier in the development cycle. In other words, engineers can run more iterations in the lab, reserving the test track for final validation.

The Flat-Trac Ride Comfort Roadway enables testing to be performed with a vehicle's engine turned on or off; driving in gear or towing in neutral; or with wheel hubs attached or detached. This permits isolation and analysis of vibration transmissibility from sources throughout a vehicle, including suspensions, tires and powertrains. The roadway system also enables the isolation of differential vibration by varying the speed of individual flat belts to simulate cornering.

Advanced benchmarking and tuning of active and semi-active suspensions are made possible with the system's four moving belts, which enable spinning tires to provide real vehicle feedback to electronic control units (ECUs). Modification of road profiles enables the roadway system to be used for conducting evaluations of new suspension designs while they are still in the model stage. Additional applications for the system include basic rolling loss and fuel economy studies.

The new roadway system includes MTS hydraulic linear actuation, patented Flat-Trac moving belt technology, MTS digital controls and MTS TestSuite software. The hydraulic actuators apply ±50mm of vertical displacement to vehicle tires at accelerations up to 20*g* and frequencies up to 50Hz. Flat-Trac moving belts enable the vehicle to run at speeds up to 180km/h (112mph), ensuring correct stiffness at each tire. Real-time controller feedback loops enable highly accurate replication of real-world driving conditions via time-history playout or synthetic (programmed) inputs. In addition, the system can integrate both human and autopilot drivers, and an automated track and wheelbase positioning system accommodates a wide variety of vehicle geometries and facilitates rapid testing throughput.

The new roadway system builds on the existing range of MTS Flat-Trac roadways, which includes the Flat-Trac Dynamic Roadway and the Flat-Trac Handling Roadway. This roadway range, in turn, belongs to an even larger portfolio of MTS Flat-Trac solutions, which employs patented flat-belt technology to address applications ranging from tire force and moment testing to aerodynamic simulation. All these solutions are backed by MTS's global service and support organization, which provides local, responsive service; advanced test consulting; and complex systems integration expertise.

Overall the new Flat-Trac Ride Comfort Roadway is designed to bring affordable, high-fidelity testing into the test lab, providing a balanced, practical and efficient solution for ride comfort evaluation, benchmarking and tuning. It will help test engineers meet increasingly complex ride comfort evaluation demands, accelerate lab-based testing, and reduce the reliance on prototypes and expensive proving ground testing.

Body count

WANT TO MAXIMIZE NON-LINEAR FLEXIBILITY IN MULTIBODY DYNAMICS SIMULATIONS? INTRODUCING ADAMS MAXFLEX

In recent years, greater emphasis has been placed on high-speed, lightweight and precise mechanical systems. Often, these systems will contain one or more structural components for which deformation effects are paramount for design analysis. In those cases, including the flexibility for those key components results in more precise loading predictions and improved system performance prediction.

Flexible bodies in Adams

Adams/Flex has been used by Adams users for many years to include linear flexibility in multibody dynamics systems, allowing them to capture relatively small deformation of flexible components (up to roughly 10% of the characteristic length) during a simulation.

However, when it comes to components with geometric or material non-linearity, like the twist beam in a suspension system or engine mounts, Adams/Flex does not provide the capability to cope with non-linearity in the simulation.

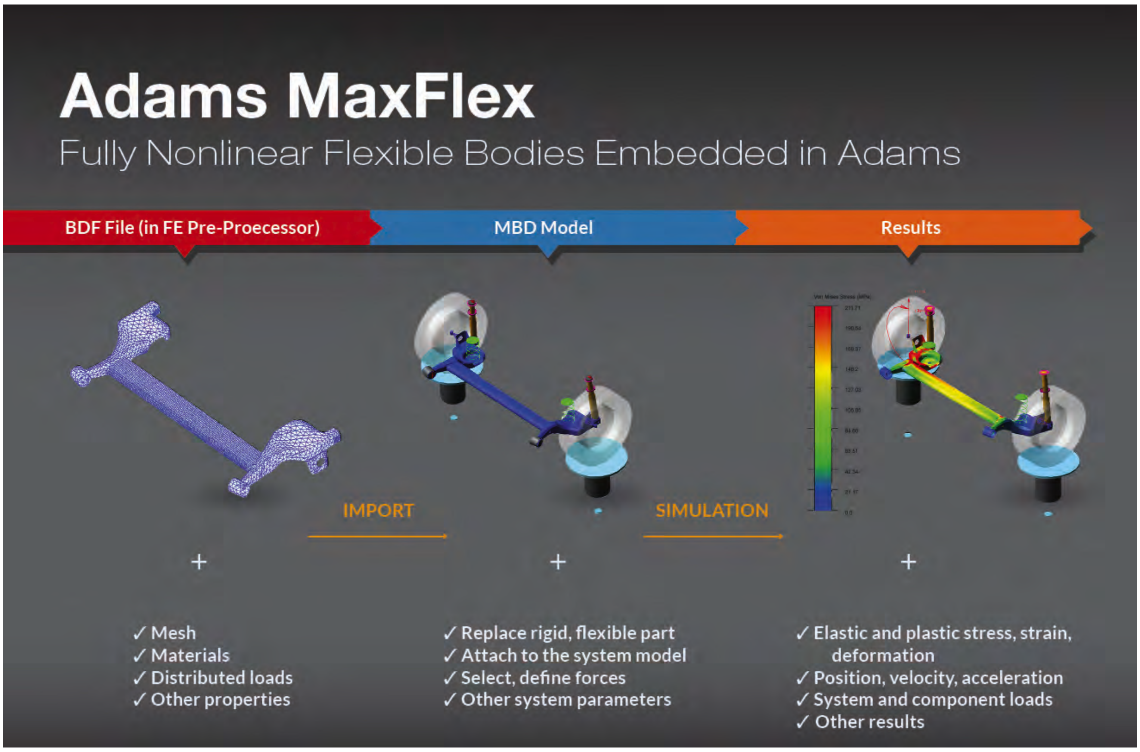
In such a scenario, engineers typically choose one of two options. The first option is to export the dynamic loads from the Adams simulation, and to then use them as the boundary conditions for subsequent non-linear FEA analysis. While it is a more realistic prediction of the non-linear stress/strain behavior than recovering stress/strain in the Adams/PostProcessor with Adams/durability, it still doesn't answer the question: what if the non-linear behavior of those parts is affecting the behavior of the rest of the multibody dynamics model, thus influencing the loads in the system? In this case, you won't get accurate boundary conditions/loads to perform the downstream non-linear FEA analysis, which fundamentally means you will not be able to simulate those systems precisely.

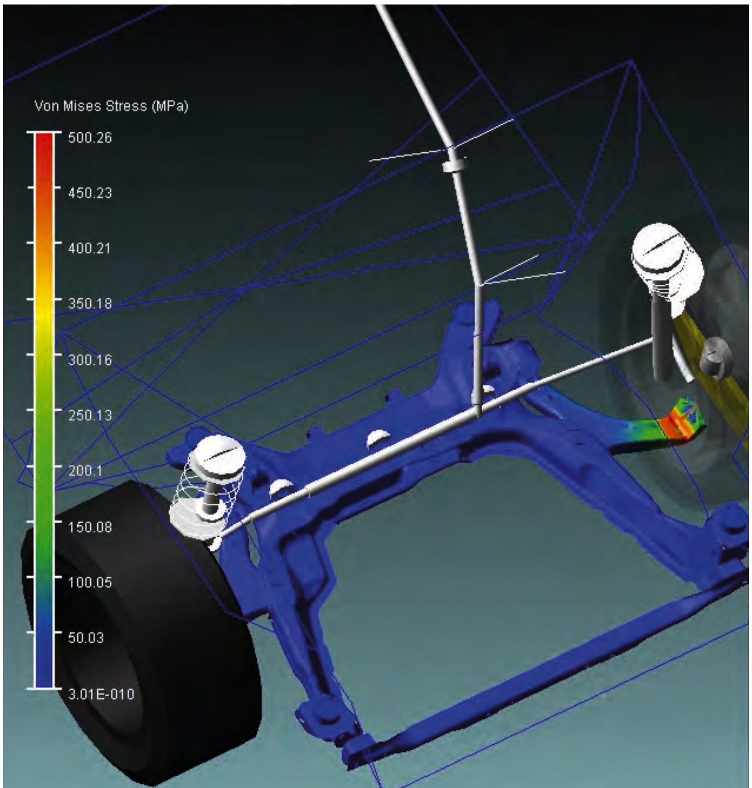
The second option is to represent the non-linear component(s) by some means other than a single linear flexible body. Discretizing the component into a set of rigid bodies or linear flexible bodies might suffice for geometric non-linearity, but can be inconvenient or otherwise quite costly in terms of pre-processing time for many users and problems. The Adams FE Part feature addresses those inconveniences but has limitations that might not make it a practical option for some problems, especially those that require shell or solid elements. Furthermore, none of these options are practical if material non-linearity is important to the problem.

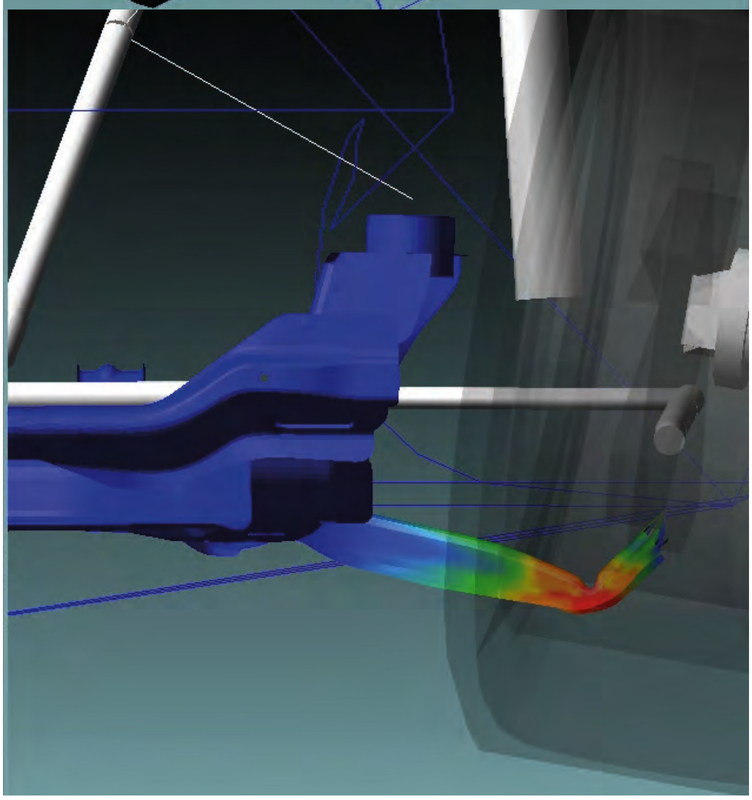
Hence, to incorporate the non-linear flexibility into multibody dynamics systems, MSC Software has introduced a new methodology/tool for its users.

The New Adams MaxFlex

The Adams flexible body has a new non-linear option, which allows for the representation of geometric non-linearity (i.e. large deformations), material non-linearity, and boundary condition non-linearity. The option is based on implicit non-linear finite element analysis. It is not MSC's intention to provide broad finite element pre- or-post-processing capabilities within the Adams







environment; rather, the focus is on providing a solution for problems where the non-linear behavior of some parts and the motions and loads of the rest of the multibody dynamics (MBD) model influence each other, making accurate results impossible or impractical through separate MBD and FEA analyses. While FEA technology is used to represent and solve the non-linear flexible body, it is embedded wholly within Adams. No additional FEA software is required to solve the model; this is not a co-simulation.

"We see potential use of MaxFlex in durability events, where permanent deformation of suspension components alters the load path and loads, which we were not capturing using MNF bodies. Having this capability in the MBD environment would help us in generating more realistic loads earlier in the program," explains Chandra Tangella, loads analysis engineer at Fiat Chrysler Automobiles.

MaxFlex can be used in any scenario where the engineer wants to capture non-linearity in the multibody dynamics model. For example, it can be used to simulate twist beam suspensions, stabilizer bars, coil springs, suspension bushings, rubber mounts, lower control arm buckling, and so on.

There are a few benefits of MaxFlex compared with linear flexible body or co-simulation technologies. For example, by using Adams MaxFlex, an MBD analyst can increase model accuracy by including non-linear structural behavior; it is a streamlined workflow, similar to Adams/Flex; and simulation is conducted entirely in Adams, saving time and cost. In addition, there is shared memory parallel support to increase simulation efficiency, it is easy to set up models and run simulations, and no third-party tool is needed to generate animations with both rigid and non-linear flexible parts, since it can be done in Adams/PostProcessor.

LEFT: **THE ADAMS FLEXIBLE BODY HAS A NEW NON-LINEAR OPTION, WHICH ALLOWS FOR THE REPRESENTATION OF LARGE DEFORMATIONS, MATERIAL NON-LINEARITY AND BOUNDARY CONDITION NON-LINEARITY. MODEL PROVIDED BY VOLVO CARS**
BELOW LEFT: **EXAMPLE OF AN ADAMS MAXFLEX WORKFLOW**

Body flexibility

LMS IS OBJECTIVELY QUANTIFYING THE IMPACT OF BODY STIFFNESS CHARACTERISTICS USING THE BODY FLEXIBILITY METHODOLOGY

Automotive manufacturers are constantly pressured to design eco-friendly cars that consume less fuel and produce lower emissions. Reducing weight has a positive impact on the fuel economy of a vehicle, but it might also affect other functional performance aspects, such as noise, vibration and harshness (NVH), comfort, crash and handling performance.

To successfully design a weight-efficient body, precise vehicle performance targets need to be set. This is particularly complex for vehicle handling, as both objective and subjective metrics define the actual performance. Engineers need to understand the relationship between vehicle dynamics and the body stiffness characteristics. But the current simulation technologies cannot unveil this interaction in a reliable way. On top of that, most measurement technologies don't allow this interaction to be objectively quantified, although drivers can subjectively perceive it.

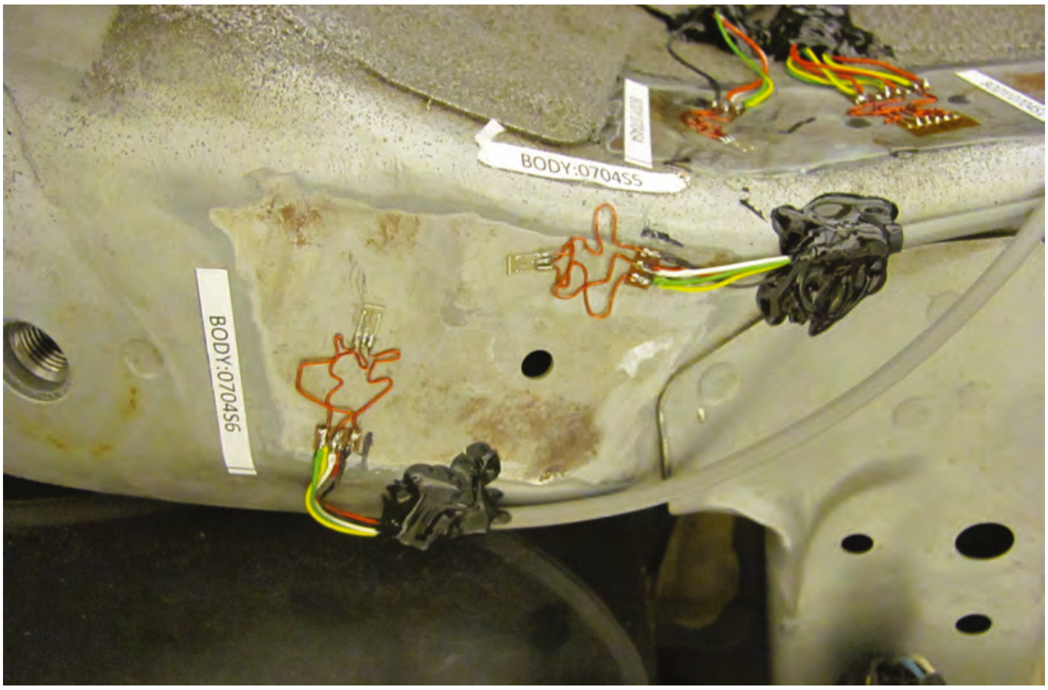
Due to the lack of objective input from either test or simulation, engineers often improve the body design for vehicle dynamics performance based on experience. This can be inefficient and can lead to undesired and expensive body changes late in the vehicle development process.

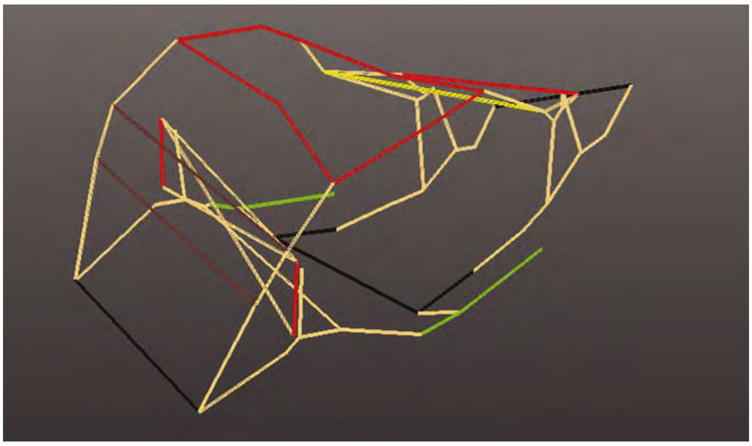
The body flexibility method, an advanced test-based technology, enables identifying the time-domain body load distribution, as well as the car body deformation, during vehicle handling maneuvers. As this method identifies the loads acting at each connection between suspension and body, it provides far more detailed information for the evaluation of the vehicle dynamics performance than the information available from objective global vehicle performance indicators – such as the lateral acceleration, the yaw-rate or the roll angle. These result from the combined effect of all loads on the body structure, and typically don't allow for quantifying objectively the impact of changing body stiffness characteristics on the vehicle dynamic performance.

RIGHT: **DATA ACQUISITION FOR BODY LOAD IDENTIFICATION IN VEHICLE DYNAMICS MANEUVERS**

The methodology combines time-domain load identification and time-domain body deformation analysis. The time-domain load identification is based on an inverse approach that uses strain responses measured on the car body. After precise calibration measurements that establish the strain-to-force relationships, the operational strains acquired on the test track can be converted into time-domain loads at each interface node of the suspension with the body. This time-domain body load distribution is impacted when the body stiffness characteristics are modified. Changes in load build-up timing, build-up linearity, and the total force level, can be identified. Using those results, engineers can gain insight into the mechanism that defines the relation between the body stiffness characteristics and the vehicle dynamic performance. This objective data can also be used for enhanced full vehicle target setting procedures and to explain the driver's subjective perception.

The time-domain body deformation is analyzed by applying the time-domain body loads to a test- or simulation-based car body model. For test-based models, dedicated testing and analysis procedures are used to accurately represent the car body quasi-static stiffness properties, including both the global dynamics (lateral bending, vertical bending, torsion, and more) and the local flexibilities (local suspension attachment point flexibilities). The calculated time-domain body deformation can be visualized and synchronously animated with on-track measured handling data for detailed analysis of the car body deflection during each maneuver. The body deformation can be decomposed into contributions of individual body stiffness characteristics, to evaluate the importance of, for example, the lateral, torsional, or local attachment point stiffness. These results support the design of targeted structural body modifications that enhance the vehicle dynamic performance.





ABOVE: **BODY STRAIN MEASUREMENTS**
LEFT: **BODY DEFORMATION DURING MANEUVERS**

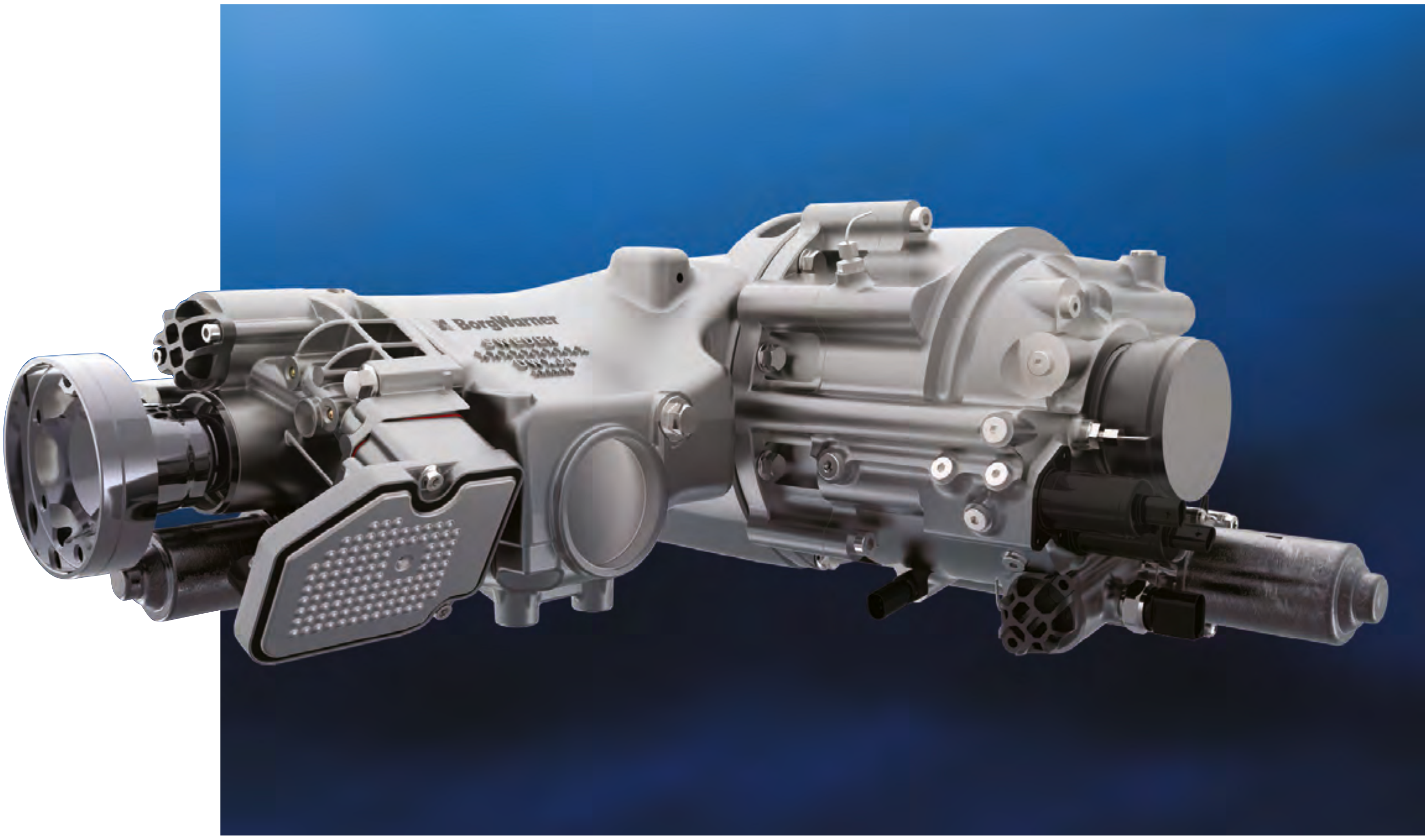
For example, a vehicle gets better subjective ratings for its transient roll behavior after adding a body reinforcement. When the roll angle and roll velocity are investigated, engineers might find minor differences that relate to the changed subjective ratings, but these don't provide sufficient insight into exactly how reinforcing the body affects the roll behavior. The investigating of the time-domain body loads, however, indicates that the application of the body reinforcement results in a redistribution of the loads between suspension and body. As the forces that counteract the body roll motion are re-distributed over load-paths that act fast (such as the struts or dampers) and load-paths that act slower (such as a stabilizer bar) – the transient roll behavior is altered. With that insight, the engineers understand the physical effect of the reinforcement and can link the objective load data to the changed subjective rating. In addition, the results highlight that a lack of body stiffness limits the performance of the suspension, and indicate which suspension components are most affected by the flexibility of the car body structure.

To understand which body characteristics induce the observed changes in vehicle performance, the (modified) body deformation during the maneuver is also analyzed. After decomposing this body deformation into contributions of individual modes or body characteristics, engineers can identify which body characteristics are most excited during the maneuver; even more importantly, which body characteristics are affected by the implemented body reinforcement. In this way, the engineers are able to gain insight into the relative importance of body characteristics for a specific vehicle performance and how a lack of body stiffness can influence the vehicle performance.

This test-based approach provides objective data that helps engineers get much more insight into the mechanisms behind vehicle dynamics performance, even for complex scenarios, such as a full vehicle evaluation with changed body stiffness. On top of that, this approach enables identification of which body stiffness characteristics are important for the full vehicle performance, and how they can limit suspension performance.

A new way ahead

BORGWARNER'S COMPACT TORQUE VECTORING TECHNOLOGY COMBINES ENHANCED HANDLING WITH VERSATILE PRODUCTION



ABOVE: **BORGWARNER'S COMPACT TORQUE VECTORING (CTV) TECHNOLOGY HELPS TO IMPROVE HANDLING, STABILITY AND VEHICLE DYNAMICS**

Almost since the birth of the automobile, the use of differential gears has been one of the fundamentals of vehicle handling, allowing the relative speeds of the driven wheels to be adjusted during cornering. As a supplier of numerous drivetrain technologies, BorgWarner has led the way with advanced developments such as all-wheel-drive (AWD) systems, electronic limited-slip differentials, hybrid electric drivelines, and torque vectoring systems. Its latest product, Compact Torque Vectoring (cTV), offers the next step forward in efficient drivetrain solutions.

The cTV technology builds on BorgWarner's expertise in on-demand AWD applications. To meet the ever-increasing demand for AWD solutions across all vehicle segments, BorgWarner has developed a number of technologies such as the highly successful AWD coupling, which automatically distributes torque from the primary driven axle to the second axle when required. cTV takes this know-how to a new level by inducing a yaw moment into a cornering vehicle, offering a more progressive approach to tracking stability and safety compared with systems such as electronic stability control (ESC).

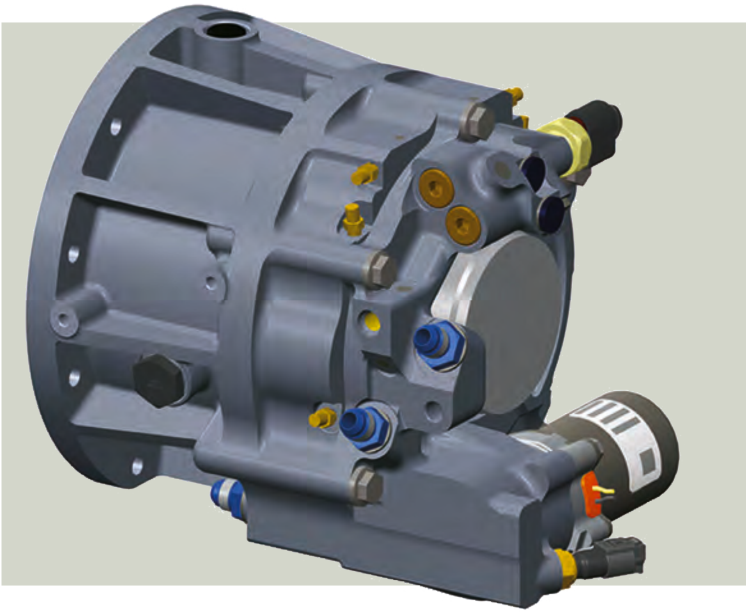
While an advanced driving assistance system such as ESC applies the brakes when it detects a loss of steering control, cTV changes the torque distribution between the left- and right-hand wheels to pre-emptively improve handling and safety. This setup results in considerably faster cornering compared with brake-based systems.

Stability within a split-second

Controlled changes to the torque distribution between the wheels on the left- and right-hand side are used to improve the consistency of steering wheel input versus yaw rate. While the total drive torque remains the same, the amount of differential drive torque is determined by vehicle dynamics software, using input from different sensors for yaw rate, lateral acceleration, wheel speed and steering angle.

BorgWarner's demonstration vehicle features a standard front-to-rear AWD coupling and a modified rear differential, with the cTV unit mounted on the left-hand side of the differential. The cTV unit consists of two sun gears and 12 planet gears. Pairs of 19-tooth and 21-tooth planet gears operate on six concentric shafts surrounding the two 76-tooth sun gears, transmitting torque between the differential case and the left-hand driveshaft.

When triggered by a reversible centrifugal electrohydraulic (CEH) actuator based on AWD coupling technology, torque can be transferred



ABOVE: **THE MODULAR DESIGN ALLOWS LOW-IMPACT PLATFORM INTEGRATION, AND THIS FACILITATES THE USE OF THE UNITS IN APPLICATIONS ACROSS DIFFERENT VEHICLE PLATFORMS AND MODELS**
LEFT: **THE CTV UNIT HAS A NET WEIGHT OF JUST 13KG, A LENGTH OF 183MM TO THE DRIVESHAFT, A HEIGHT OF 207MM AND A WIDTH OF 198MM**

between the 19-tooth wheel and the 21-tooth wheel by applying a clamping force to a small wet clutch located at the end of each planet shaft. If no clamping force is applied, the cTV is inactive and the rear drive unit works in the traditional manner. The clutch clamping force is obtained via annular hydraulic pistons located on each clutch.

It is possible to obtain the required torque-vectoring effect by controlling the hydraulic pressure. By simultaneously applying force to the clutches of three of the shafts, additional drive torque is transferred to the left-hand rear wheel to increase its speed. Correspondingly, the speed and torque at the right-hand rear wheel are reduced, and the resulting yaw moment causes the vehicle to veer right. Alternatively, by pressurizing the other three clutches that slow down the left-hand side wheel, its torque and speed decrease, the differential automatically increases the torque and wheel speed on the right-hand side, and the resulting yaw moment causes the vehicle to veer left. While the vehicle is running straight ahead, no hydraulic pressure is applied, so there is no clutch activity.

Benefits for OEM and driver

Some of the principal advantages of cTV for OEMs are its compact size, its low weight and its versatility. The cTV unit has a net weight of just 13kg, a length of 183mm to the driveshaft, a height of 207mm and a width of 198mm. At the same time, its compact dimensions and its location at the side of the differential unit help with vehicle packaging. Since the torque vectoring components are packaged on one side of the axle differential, carryover axle components can be used for reduced system cost.

The modular design allows low-impact platform integration, and this facilitates the use of the units in applications across different vehicle platforms. In addition, the cTV components can equally be applied to AWD systems based on rear-wheel and front-wheel drive. As a simple 'bolt-on' unit on the rear differential, cTV can allow the same base vehicle or platform to be offered, with or without optional torque vectoring.

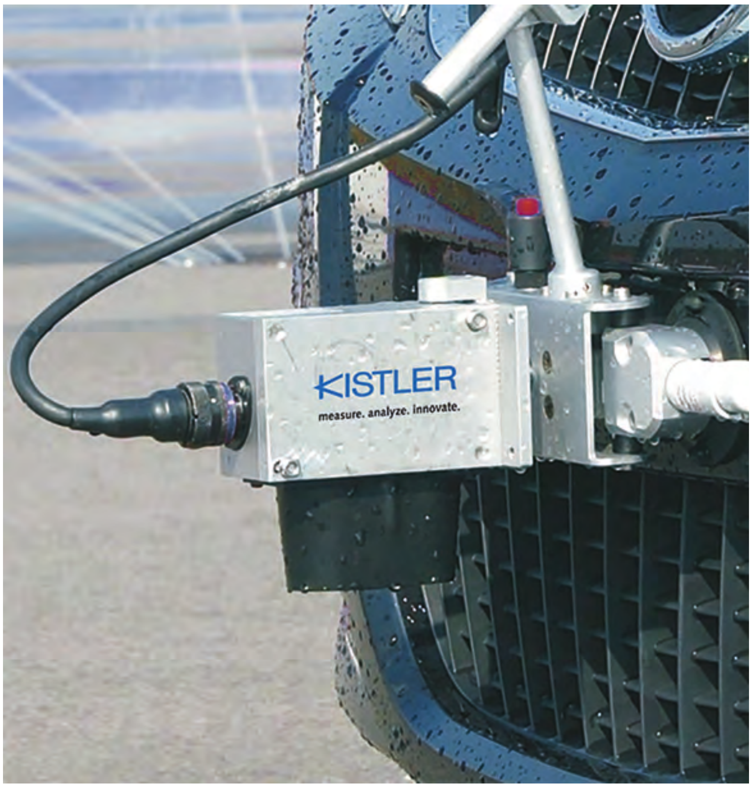
Moreover, direct actuation using the reversible CEH actuator is less sensitive to contamination and more robust than systems comprising control valves. The flow is directed in two directions, thus eliminating the need for an additional valve. In addition, hydraulic actuation provides excellent torque accuracy and low hysteresis, while allowing easy pressure sensing and detection by the pressure sensor.

BorgWarner's new technology also offers benefits for the driver. A compact torque vectoring system helps to improve handling, stability and dynamics across all vehicle sectors. With a torque vectoring capacity of up to 1,000Nm, the system can distribute additional torque in fractions of a second, which enhances dynamics and safety.

The technology controls the torque distribution in critical driving situations such as accelerating and steering into a corner, and provides smoother steering responses and much less steering input than similar cars without torque vectoring. As a result, it offers superior vehicle handling, particularly on slippery road surfaces.

Combined sensors

BY USING A MOTION SENSOR AND A MEASUREMENT STEERING WHEEL, DYNAMICS TESTS CAN BE QUICKER, SIMPLER AND MORE RELIABLE



RIGHT: **KISTLER'S CORREVIT L-350 AQUA SENSOR IN SITU DURING AN AEB TEST**

Driving dynamics tests often involve highly complex motion sequences and therefore require proven test methods and equipment. Standardized tests are especially important when it comes to the assessment of vehicle driving behavior.

A typical example of such a standard test is the open-loop test 'braking in a turn', as specified by ISO 7975. During this test, a vehicle's directional behavior is determined when it moves from a steady state (i.e. the steady-state circular course drive) into a non-steady state following a braking action. Vehicle engineers must know the exact effects of directional behavior to enable them to develop safe and comfortable vehicles.

Typical measurands of this test method are steering angle, brake system pressure, longitudinal and transverse acceleration and speed, yaw velocity, slip angle, and pitch and roll angles.

The test procedure begins with the steady-state circular course drive, performed on a specified radius. The driving speed is then increased until the stipulated transverse acceleration is reached. These steer angle and speed values serve as reference values for the evaluation of the next in the series of tests. Fixing the steering angle facilitates the execution of the test, as it enables the steering angle to be constant, even when the braking action induces deceleration.

Often an accelerometer is aligned to the vehicle's y-axis to measure transverse acceleration. However, the accelerometer only measures the lateral acceleration and it must be corrected by applying the roll angle to determine transverse acceleration. If you apply an analog accelerometer to measure longitudinal acceleration, it must be corrected by the pitch angle. After determination of these reference values, the braking action during the steady-state circular course drive will be performed.

When the transverse acceleration given by the standard is reached, braking is initiated at a constant steering angle. The test is performed with various longitudinal decelerations. For future evaluation, it is necessary to determine the rise time of the brake pressure.

Figure 1 shows the course of a braking maneuver performed during the steady-state circular course drive. When braking commences, the vehicle rolls around its y-axis for a short time, due to the decreasing transverse acceleration. As a consequence, the decreasingly active lateral force springs back to its original position.

The determined reference values of the steady-state circular course drive, as well as the measurement values from the braking action, are used to evaluate the parameters for the steerability and the yaw behavior as a function of the braking characteristics.

Another test procedure for the assessment of driving characteristics is the ISO 7401 lateral transient response test, for determination of the transverse dynamic behavior of a vehicle.

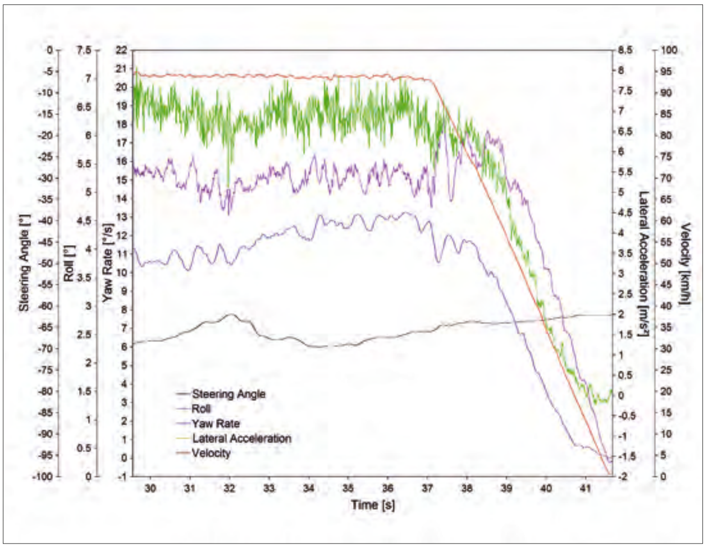
Different test methods, such as step-steering input, sinusoidal input (one or more periods), random input and pulse input, enable characterization in the time range as well as in the frequency range.

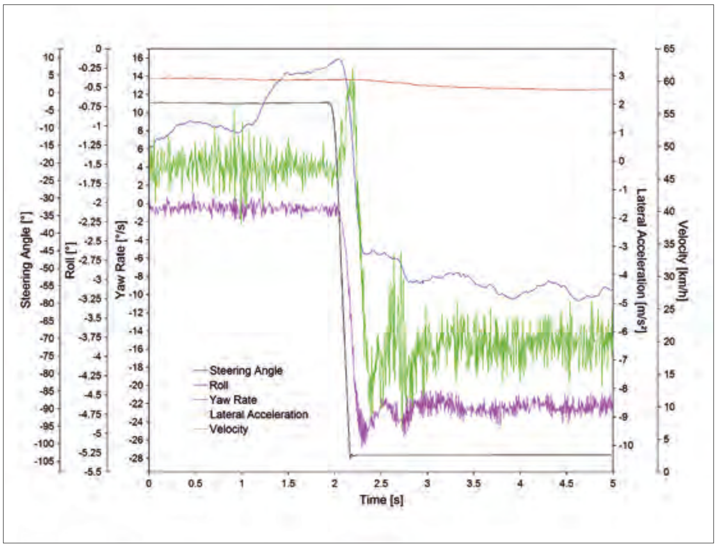
Important parameters in the time range are: time shift between steering wheel angle, transverse acceleration, yaw velocity and the magnification ratio of the yaw velocity.

Important parameters in the frequency range are: transverse acceleration related to the steering wheel angle, and yaw velocity related to the steering speed.

To determine these correlations it is necessary to measure the following parameters: steering angle, steering moment, longitudinal acceleration, yaw velocity, slip angle, longitudinal and transverse speed, and roll angle.

For the determination of time behavior, step steering or sinusoidal input over a certain period may be applied. Step steering input means a quick turn-in of the steering wheel when driving straight ahead, applying a steering angle that has been determined in a pre-test, and





which must be held constant for some seconds. In the pre-test (the steady-state circular course drive), a steering angle for a transverse acceleration of $4m/s^2$ was determined. The sinusoidal input, on the other hand, requires a steering input over a period with a steering frequency of 0.5Hz.

Figure 2 shows the course of yaw rate, roll rate, longitudinal acceleration and longitudinal speed as a response to the step steering input.

Random input provides measurement values for evaluation in the frequency domain; it means an arbitrary input of the steering angle for a longer time period to gain enough measuring points per frequency. Another test option is pulse input, which requires a steering input of a triangular pulse followed by a steering movement toward straight-ahead driving. A third possibility is a steering input of several sinusoidal steering movements, with a frequency starting at 0.2Hz and rising to 2Hz at constant steering angle maxima.

With the help of this test procedure it is possible to characterize part of the transverse dynamic behavior of the vehicle. The required measurands can be determined with the recently developed Correvit S-Motion sensor and the Kistler MSW (measurement steering wheel) sensor.

A Correvit S-Motion sensor is capable of delivering all measurands that are relevant for vehicle dynamics testing: longitudinal and transverse speed; angles (slip angle, pitch and roll angle); acceleration in three directions; direction detection; and position data via GPS.

The high measurement frequency of 500Hz and a novel algorithm help to reduce signal noise substantially and enable a constant signal delay of 6ms. The sensor can be easily installed on the vehicle using the included mounting equipment (suction or magnet holders). A considerable advantage is the built-in inertial measurement unit, which makes the use of external acceleration and yaw rate sensors redundant and saves the user considerable setup time as it is not necessary to mount, adjust and configure these additional sensors.

The S-Motion sensor electronics can be configured to perform various calculations to the point of interest, which means that no post-processing of the measurement data is needed. Most interesting is the fact that no laborious running-in procedure is required. Just align the S-Motion sensor to the vehicle's longitudinal axis and the complete adjustment of speed sensors, yaw rate sensors and acceleration sensors is done.

Kistler's measurement steering wheel (MSW sensor) is a good tool for measuring steering moment, steering angle and steering speed. It is installed in the vehicle between the steering shaft and the steering wheel. To enable universal application, MSW sensors can be equipped with an exchangeable adapter for connection to the steering shaft. The wheel does not impair the airbag function, and a universal mount enables quick mounting of the MSW sensor to the original steering wheel.

Furthermore, the MSW sensor may be combined with a special steering angle stop, which enables the user to fix the steering angle to a set point and to perform steering movements between freely adjustable limits. Locking levers fix the steering angle. Releasing the levers immediately unblocks the steering wheel, allowing normal driving.

A multitude of driving dynamics measurands must be determined to perform standardized test procedures, which often means that the test vehicle must be equipped with a lot of measurement instrumentation. The more instruments that are required, the more error sources will be present, and the longer the setup time.

Especially these days, quick and easy mounting, reproducibility, plausibility of measuring results, high accuracy and comfortable operation of the measurement instrumentations, play a decisive role in dynamics tests. The combination of the Correvit S-Motion sensor and the Kistler MSW sensor provides exactly this.

FIGURE 1 (ABOVE LEFT): **THE COURSE OF A BRAKING MANEUVER PERFORMED DURING THE STEADY-STATE CIRCULAR COURSE DRIVE**

FIGURE 2 (ABOVE RIGHT): **THE COURSE OF YAW RATE, ROLL RATE, LONGITUDINAL ACCELERATION AND LONGITUDINAL SPEED AS A RESPONSE TO THE STEP STEER INPUT**

Effective code generation

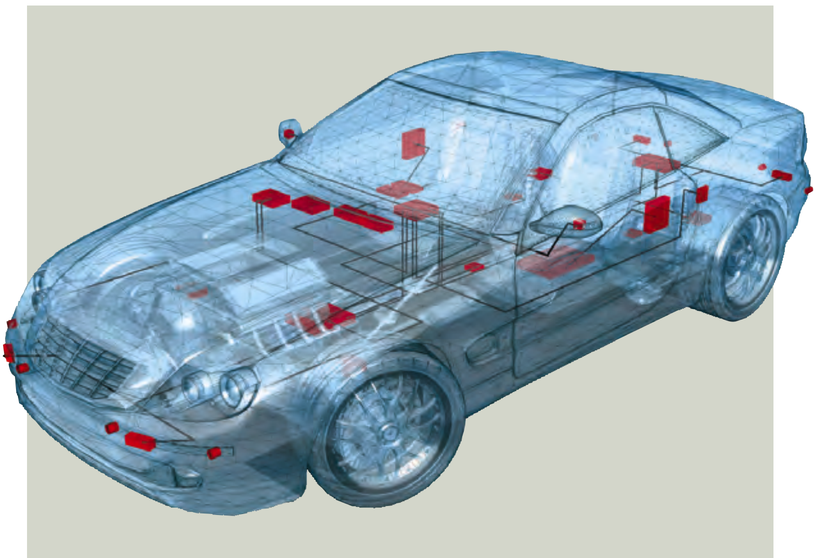
DSPACE HAS CONTINUED ITS DEVELOPMENT OF TARGETLINK, ITS PRODUCTION CODE GENERATOR, TO ENSURE IT REMAINS AN INDUSTRY BENCHMARK

In the development of software for automotive ECUs, model-based development and automatic production code generation have become standard industrial methods all over the world. Ever since its launch in 1999, TargetLink, dSPACE's production code generator, has been a driving force in this process. Today, TargetLink is the world's number-one production code generator and is used by virtually all major companies in the automotive industry. TargetLink generates production-ready ANSI-C code for ECUs straight from MATLAB/Simulink/Stateflow.

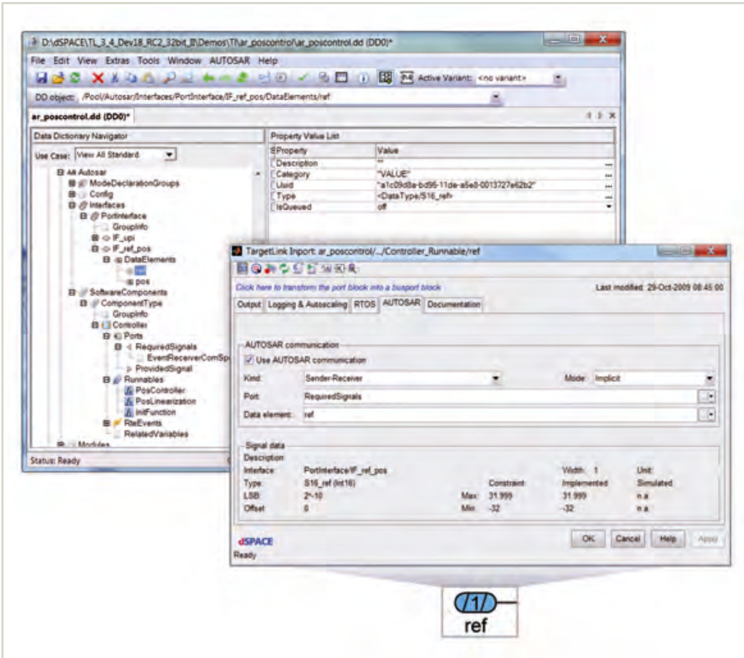
The list of TargetLink applications covers all areas of the vehicle, including the powertrain, chassis, driver assistance, comfort, and active and passive safety systems. TargetLink's special strengths are the optimized code it generates and its high reliability, process integratability, and support of standards such as Autosar, OSEK, ISO 26262 and ASAM MCD-2 MC (ASAP2).

TargetLink has been specifically designed for production-quality autocoding. It can easily match the efficiency of code produced by human programmers in terms of memory consumption and execution speed – without compromising readability. The generated code can be fixed point or floating point, or a mixture of the two. Code efficiency is one of TargetLink's great strengths, and code configurability is another. Whether users need to adapt the memory layout, or integrate legacy code or required function interfaces, TargetLink can handle it all thanks to its range of configuration options.

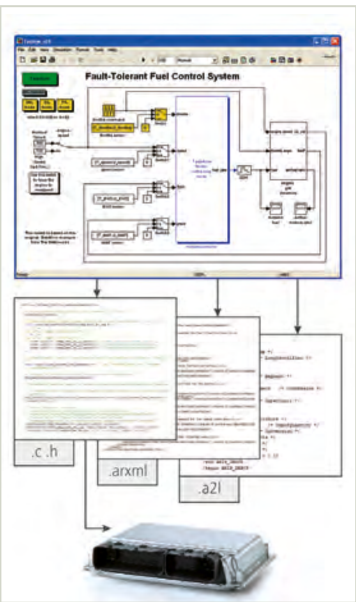
Although automatic code generation produces virtually flawless results compared with manual programming, the generated code and the underlying specification still need to be tested. TargetLink provides powerful and intuitive functions for code verification. The generated code can be tested in the Simulink/TargetLink environment by comparing the simulation of the block diagram-based function model (model-in-the-loop simulation, MIL) directly with the simulation of the



ABOVE RIGHT: **TARGETLINK CAN GENERATE PRODUCTION CODE DIRECTLY FROM SIMULINK/ STATEFLOW**
RIGHT: **SYSTEMS THROUGHOUT A VEHICLE ARE ALL POTENTIAL TARGETLINK APPLICATIONS**



LEFT: **AUTOSAR SUPPORT IN TARGETLINK**
BELOW LEFT: **GENERATING PRODUCTION CODE AND DESCRIPTION FILES FROM SIMULINK/TARGETLINK MODELS**



production code on a development PC (software-in-the-loop simulation, SIL). TargetLink makes it extremely easy to compare the results of these simulations to determine whether the algorithm and the code have the desired behavior.

One prominent example of TargetLink's automotive focus is its native integrated Autosar support. TargetLink provides a wide range of functions for designing, autocoding and testing Autosar-compliant software components. Autosar round trips with other tools are particularly efficient thanks to the TargetLink Data Dictionary, with its wide range of editing, diff and merge, and import/export functions.

When TargetLink is combined with dSpace SystemDesk, data is exchanged in component containers to provide yet another option for making the Autosar-compliant development process easier, more transparent and more efficient.

An increasing number of functions in modern vehicles are related to safety, and this makes specific demands on the tools used for development. TÜV Süd, an independent German certification authority, has certified TargetLink's suitability for the development of safety-related systems. After comprehensive testing, the TÜV experts confirmed that TargetLink can be used for software development according to ISO 26262, IEC 61508 and derived standards.

Driving simulators

MECHANICAL SIMULATION EXPANDS ITS RANGE OF DRIVING SIMULATORS TO INCLUDE PLATFORMS SPECIFICALLY FOR ENGINEERS

Motion-based flight simulators were invented in the mid-1950s as a means to train military and commercial pilots in a safe and cost-effective manner. Since that time, automotive engineers have spent thousands of hours writing proposals to convince management to invest in simulators for ground vehicles. In most cases, their proposals were rejected based on return on investment, performance limitations, and operating cost concerns. Aviation simulators easily trumped these objections since the cost of a flight simulator facility is minimal compared with the cost to train a few hundred pilots. Preventing a single plane crash easily justifies the cost of a comprehensive, simulation-based flight training program. It is also worth stating that hexapods – the most common 6DOF platform used in motion-based simulators – are well suited to simulate the yaw, pitch and roll motions of airplanes.

Driving simulators have now reached a level of refinement and sophistication where they are powerful, economical and necessary tools to meet the challenges faced by a rapidly changing automotive industry. New driving simulators, such as Mechanical Simulation's QuadDS, feature high-fidelity vehicle dynamics, interfaces to standard engineering tools including MATLAB/Simulink, high-quality visualization systems, and motion platforms optimized for development driving. The engineering driving simulator is designed for medium-sized labs with a small team of engineers – ideal for rapid prototyping and A-B comparisons early in the development process.

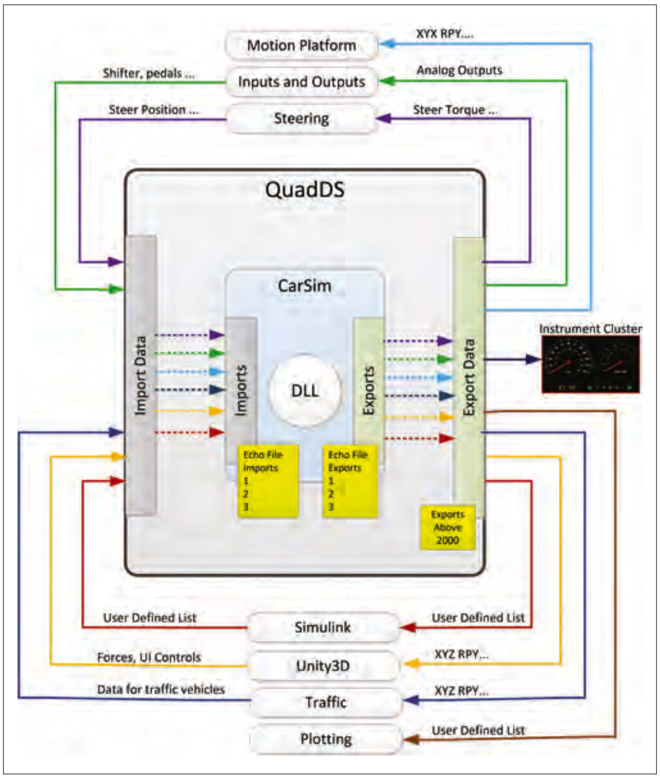
"The QuadDS platform," explains Len Johnson, senior driving simulator engineer at Mechanical Simulation, "provides another dimension to engineers. CarSim and TruckSim models can be driven and evaluated in virtual environments well before hardware is available. This allows early confirmation of targets and assessment of vehicle model quality. Since engineers now perform first-cut tuning tasks and evaluate hardware tuning kits on driving simulators, they are able to quickly and efficiently complete final tuning tasks once production-ready hardware becomes available. Engineering driving simulators have now reached a price point where every engineer can experience a representation of their designs early in the product development process."

The idea of automotive driving simulators gained momentum in the late 1990s as the cost of industrial automation, computer, and visualization technologies plummeted and performance escalated. As soon as the first large facilities were commissioned, the industry realized that simulating automobiles is much more challenging than simulating airplanes. Early attempts at automotive driving simulators left drivers underwhelmed and often victims of simulator sickness. From the complex interaction at the tire/road interface, to the high visual flow rate drivers experience compared to pilots, to the relatively unrestrained seating position of passenger cars, every aspect of applying hexapods as the motion platform for engineering driving simulators required new and innovative thinking.

The fundamental differences between driving and flying drove automotive simulators to an "all or nothing" approach that permeated the driving simulator industry for several decades. At the high end, this thinking led to the construction of a handful of multimillion dollar driving simulators housed in massive facilities and staffed by dozens of engineers and technicians. Financial realities made these simulators suitable for two major applications: (1) large government-funded human factor and driver behavior studies with drivers selected from a pool of volunteers, and (2) high-budget motorsports simulators optimized for a select number of professional test drivers. At the same time, the low end of the market produced fixed-based driving simulators targeted at the driver training market. As these devices focused on teaching basic vehicle operation, they lacked the fidelity and flexibility required for use in engineering applications.

Fast forward to 2015, we find that industry trends are converging to bring engineering driving simulators within reach of most development organizations. The most important trend, initiated by high-end motorsports organizations, is that simulation platforms must only produce the most important motions for the driving situation while minimizing or ignoring motions that do not feel natural to the driver. This thinking minimizes the use of hexapods in favor of motion platforms designed for specific applications. For motorsports applications, this refinement translates into rotary platforms capable of generating high yaw rates. For engineering, the focus is on small motion cues and precision steering/pedal systems that communicate how subtle driver inputs are translated through the road/tire interface. The next trend is the intense pressure created by economics of the automotive industry and the rapid deployment of ADAS and autonomous

BELOW: **DIAGRAM SHOWING THE ARCHITECTURE OF THE QUADDS VEHICLE DRIVING SIMULATOR**



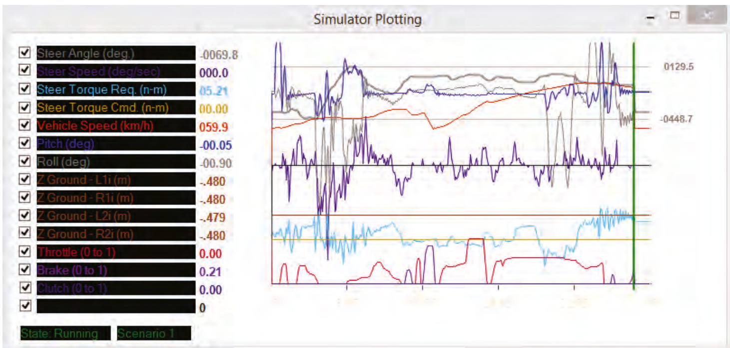
driving technologies. OEMs looking to optimize and streamline their investment in simulation technologies continually seek tools and techniques that allow them to use the same set of simulation models throughout their entire engineering development process.

The QuadDS is the first driving simulator to put all of these pieces together in a package feasible for medium-sized engineering labs. Instead of focusing on large facilities for a few anointed drivers, the simulator is designed for engineers who need to combine their vehicle simulation models and associated active controllers – brakes, suspension, powertrain – in a virtual environment. The simulator features CarSim as the vehicle dynamics platform, a MATLAB/Simulink interface, CAN ports to interface with HIL systems and vehicle controllers, and an open architecture that lets engineers integrate their own driver controls and I/O systems. Other interfaces allow engineers to integrate traffic simulation programs and high-end visualization systems that can simulate advanced sensors such as radar and lidar.

“Many of our OEM and Tier 1 customers have eliminated weeks of proving ground testing because they were able to complete multiple calibration rounds using Mechanical Simulation’s driving simulator technologies. Engineers are able to evaluate multiple configurations quickly and optimize their time at the test track,” explains Robert McGinnis, senior account manager at Mechanical Simulation. “The surprise to us is that the simulator has become more than an engineering tool – it is a communications tool that helps engineers fully investigate the nuances and limitations of their vehicle systems and share this information with their management early in the product development process.”

The future for engineering driving simulators is promising as ADAS and autonomous driving technologies are pushing the traditional test plans and automotive proving ground protocols to their breaking point. These advancements are also causing great concerns with proving ground staff tasked with performing high-speed, close quarter maneuvers to fully test a vehicle’s sensor capabilities. “When you combine high-fidelity vehicle dynamics, accurate sensor models, and virtual/augmented reality technologies, you have an ideal platform to evaluate technologies that require multiple cars to operate in close proximity to each other. By networking real and virtual vehicles in the same environment you get the best of both worlds – realistic scenarios and safe driving,” concludes McGinnis.

As sensor technologies become more demanding, the QuadDS is keeping pace by providing photo-realistic driving environments featuring realistic lighting, dynamic weather, kinematic pedestrians and bicycles, and advanced driver assistance displays.



ABOVE: **INSIDE THE REALISTIC QUADDS ENVIRONMENT**
LEFT: **PLOTTED FEEDBACK ALLOWS USERS TO TRACK PROGRESS**

Next-generation braking

ZF TRW IS HELPING OEMs MEET GLOBAL SAFETY STANDARDS THROUGH ADVANCED BRAKING TECHNOLOGIES FOR A VARIETY OF AUTOMOTIVE APPLICATIONS

A new brake technology from ZF TRW will help to meet the global industry trends of efficiency, safety and automated driving. Starting production with a major vehicle manufacturer in 2018, Integrated Brake Control (IBC) is a vacuum-independent technology that simplifies the brake system architecture while offering enhanced performance.

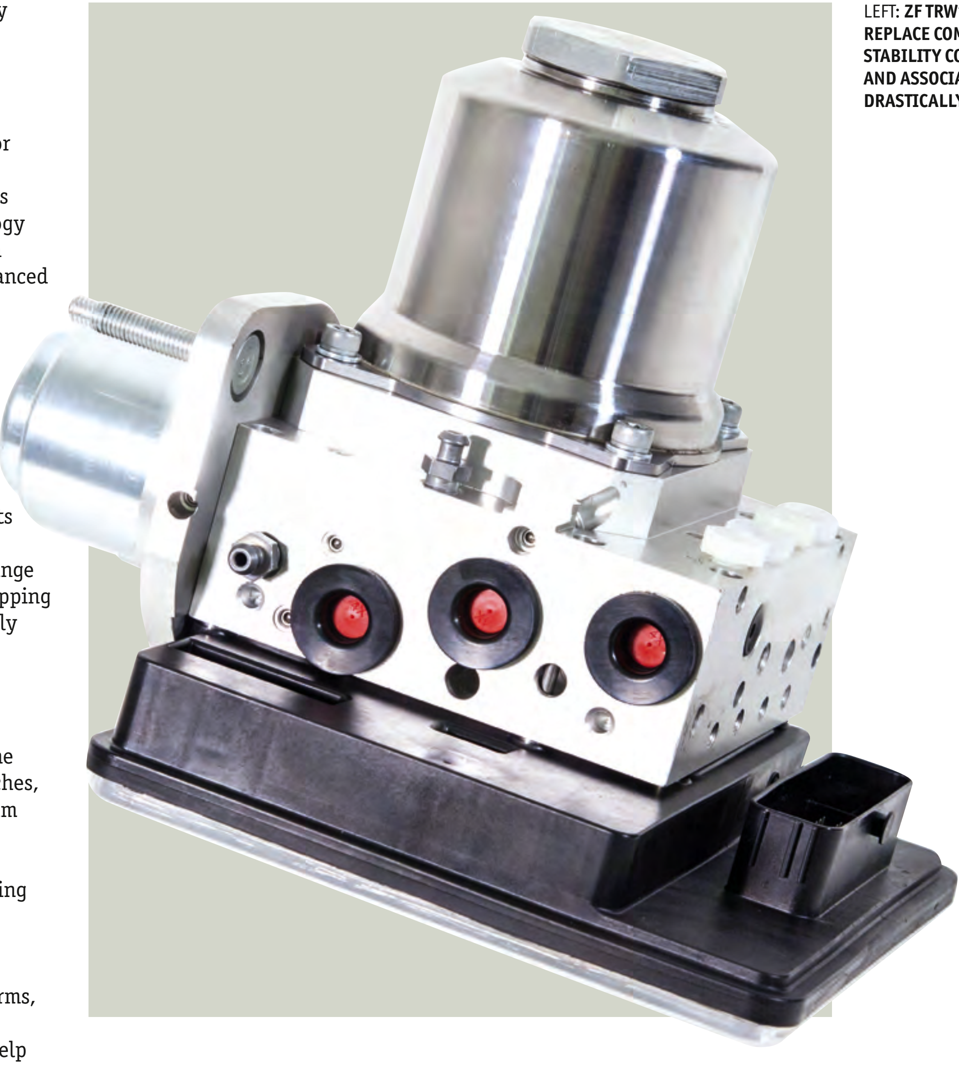
IBC supports all powertrain configurations and can integrate regenerative braking technology for hybrids and electric vehicles, helps deliver advanced safety in the form of rapid building of brake pressure for high dynamic events such as automatic emergency braking, and will support the range of brake vehicle control and stopping requirements for partially to fully automated driving functions.

IBC replaces – in a single integrated unit – the electronic stability control system along with the vacuum booster and the associated cables, sensors, switches, electronic controllers and vacuum pumps.

At the heart of the system is an actuator driven by a fast-acting motor capable of building brake pressures that translate into up to 1*g* of vehicle deceleration in less than 150ms. In practical terms, this means that compared with base brake systems, IBC could help reduce a vehicle's stopping distance at 100km/h by up to 9m during an automatic braking event.

IBC delivers on-demand braking. The technology uses a pressure pump with fluid already in the piston so that when it moves, the pressure increases immediately. Brake feel is simulated, enabling almost 100% of the vehicle's potential energy to be recuperated. The simulator enables IBC to take care of the brake blending. A sensor detects what the driver wants to do and a small chamber in the pedal provides feedback, even though the operation is completely by wire.

As no vacuum pump is needed, the technology is approximately 5kg lighter than conventional systems. In a large car this equates to CO_2 savings of around 1g/km.



LEFT: **ZF TRW'S IBC IS ABLE TO REPLACE COMPLETE ELECTRONIC STABILITY CONTROL SYSTEMS AND ASSOCIATED COMPONENTS, DRASTICALLY REDUCING WEIGHT**

ZF TRW sees the technology as a major step forward for brakes. It has tailored the system to the needs of vehicle manufacturers, helping to deliver the capabilities and functions they require. ZF TRW is also the only company that offers a fully scalable system, with a high-end version for heavier cars and another version adapted for base models.

ZF TRW has been working on vacuum-less brake systems for several years. With IBC, a key challenge was making the technology simpler to manufacture and package. By using proven technologies and production techniques, the company has produced an affordable system with elegant packaging, the right architecture and fewer components. Furthermore, IBC's additional functions considerably outnumber those of electronic stability control.

With CO_2 reduction, hybridization and automatic emergency braking now more in focus than ever before, IBC is an ideal solution to support vehicle manufacturers' goals in these areas.

Relative distance

NEW FUNCTIONS ON GENESYS'S ADMA 3.0 GPS/INERTIAL PLATFORM ENABLE RELATIVE DISTANCE MEASUREMENTS WITH ADAS

ABOVE: **CENTIMETER-ACCURATE MEASUREMENT OF DISTANCES OR RELATIVE ANGLES BETWEEN SEVERAL VEHICLES IS USEFUL FOR APPLICATIONS SUCH AS AEB TESTING**
BELOW: **THE NEW AUTOMOTIVE DYNAMIC MOTION ANALYZER HAS AN OUTPUT RATE OF 1,000HZ**

The GPS-aided Automotive Dynamic Motion Analyzer (ADMA) gyro system from Germany-based GeneSys is developed and produced specially for measurements of vehicle dynamics and driver assistance parameters in the automotive sector. The new generation of ADMA is equipped with many new features: an output rate of 1,000Hz, a data latency less than 1ms, and various CANbus and Ethernet interfaces.

The new DELTA function enables centimeter-accurate measurements between several vehicles in real time. General settings are now configured quickly and easily via a web browser. ADMA meets all the demands of industry test standards.

The ADMA permits high-precision dynamic measurement of all states of motion, including acceleration, velocity, position, rotational speed, position angle and slip-angle of the vehicle.

With ADMA 3.0, a selection of new functions are available. One of the new functions is that ADMA allows an output rate of 1,000Hz with unlimited data records and a data latency of less than 1ms. Besides CANbus interfaces, the device includes Ethernet interfaces for data output, configuration/updating and driving robot. In practice, such high data rates in real time prove particularly valuable when developing driver assistance systems. For example, at 1,000Hz, the longitudinal position of a vehicle moving at 100km/h can be spatially resolved to less than 3cm.

Another new option is the DELTA function, which even enables centimeter-accurate measurement of distances, relative speed or relative angles between several vehicles in real time, simply by interfacing two ADMAs via wi-fi. Now the setup for testing all kind of range-based sensors (e.g. radar or lidar) and ADAS systems (e.g. ACC, FCW and AEB) becomes more simple and reliable.

The general settings are configured quickly and easily via a web browser. The new web interface is loaded with new functions and replaces the previous ADMA system software.

Besides vehicle dynamics testing, the ADMA is the first choice for evaluating driver assistance systems, such as ACC, FCW, AEB and LDW. The GPS-aided GPS/inertial system meets all the demands of industry test standards.

Work together

DRIVER-IN-THE-LOOP TESTING WITH MULTIPLE DRIVER PARTICIPATION IS NOW AVAILABLE, THANKS TO SOFTWARE FROM RFPRO

RIGHT: **RFPRO'S LOW LATENCY AND HIGH BANDWIDTH TECHNOLOGY, COMBINED WITH HIGH DEFINITION ROAD MODELING, PROVIDES THE NECESSARY IMMERSION FOR REALISTIC EVALUATION BY A HUMAN DRIVER OF CHARACTERISTICS SUCH AS RIDE AND HANDLING**

When using a driving simulator for driver-in-the-loop (DIL) testing, greater realism improves accuracy of results, which in turn saves both time and money. With the growing importance of testing ADAS and autonomous system intervention in situations involving interactions between vehicles, it is no longer sufficient just to provide the necessary realism during lone vehicle events. Software developer rFpro has developed a package that combines with existing traffic software to provide convincing traffic behavior simulation and even facilitates multiple drivers sharing the same virtual environment.

DIL testing with a driving simulator produces better quality data when the driver is more immersed in the virtual environment, according to Chris Hoyle, rFpro's technical director. "During an emergency avoidance maneuver, a suitable parameter for measurement might be peak vehicle lateral acceleration, with higher values corresponding to greater driver distress," he explains. "We find that the standard deviation between the results from different tests is much greater with lower definition virtual models and lower levels of immersion. This variation means that many more tests are required to establish confidence in the results, and it also makes it much harder to identify small improvements."

RIGHT: **RFPRO IS WORKING WITH MTS SYSTEMS ON ITS NEW VEHICLE DRIVING SIMULATOR**

The increased realism from the rFpro software reduces the variation in results, minimizing the number of tests required, and is immediately evident in the behavior of the driver. "They begin to look in the rear-view mirror and reach for the indicators in anticipation; they really believe they are driving," says Hoyle.

The success of rFpro has been based on the low latency and high bandwidth of its software, which enables the effective use of simulators in the field of vehicle dynamics, ADAS and autonomous systems. As the automotive industry develops vehicle systems capable of increasing levels of autonomous intervention, those same characteristics in rFpro's products are now supporting the simulation of vehicles interacting with each other and their traffic environment.

In partnership with established suppliers of traffic software, such as Vires and Forum8, rFpro enhances the virtual traffic surrounding the test driver by adding realistic dynamic properties – including wheel travel, pitch, squat and roll – to each vehicle. These properties complement the existing properties of road position, speed, direction, and adherence to traffic rules, to create a convincing virtual environment in which the other traffic not only behaves realistically, but looks life-like too. It is this attention to detail that, as described above, helps reduce the variance of test results, and directly improves the value of the simulator to the test team.

"Active safety systems such as collision avoidance and autonomous emergency braking can be evaluated with a simulator because other virtual road users can be programmed to execute unexpected maneuvers, such as sudden braking or lane changes," says Hoyle. "However, the big step is the introduction of multiple driver participation; by linking two or more simulators through an Ethernet cable, drivers can share the same virtual environment."

Using one driver to execute maneuvers intended to provoke a reaction in the second driver is often quicker and more effective than attempting to program a suitable trigger event. The driver providing the input need not even use a simulator, but could operate from a lower-cost workstation, provided both users are running rFpro software. In the most complex situation, multiple drivers can interact with each other and any virtual traffic, which could enable even more sophisticated use of driving simulators in the future.

FREE READER INQUIRY SERVICE
To learn more about rFpro, visit www.ukipme.com/info/vdm ref. 012

Broad appeal

HAVING ACQUIRED A BROAD RANGE OF ENGINEERING SKILLS AND TOOLS, RICARDO CAN BE A DYNAMIC BRAND CHAMELEON FOR THE WORLD'S CAR MAKERS

RIGHT: **RICARDO CAN QUICKLY DECIDE WHICH VEHICLE DYNAMICS TECHNOLOGIES ARE MOST SUITABLE FOR A GIVEN APPLICATION, WITH PREDICTED RESULTS MEASURED AGAINST BENCHMARKING DATA**

Today's new vehicles not only need to look, feel, perform and sound in accordance with each auto maker's brand book, but must also increasingly meet the dynamics of ride and handling that define and underscore the brand's character. As an independent engineering partner, Ricardo needs to emulate all these brand requirements precisely.

Speak with a vehicle engineer from any of the world's quality auto makers, and it probably won't be long before they refer to the challenge of engineering each new product in a manner that satisfies the unique characteristics of the brand. For directly quantifiable or perceptible brand attributes such as performance and functionality, engineering target-setting is comparatively straightforward, even when the development challenge is complex. For more abstract attributes such as sound quality or ride and handling, however, establishing targets that satisfy the brand book can in itself be a challenge.

As an independent vehicle engineering organization, Ricardo needs to do much more than establish a set of rules for one brand; instead it needs to be able to set engineering targets that will deliver the dynamic response required of each and any auto maker.

A comprehensive benchmarking capability, including techniques such as kinematics and compliance rig testing, is essential, as is the ability to record and efficiently process the results into a database that can inform future projects. The ability to synthesize meaningful targets using this work, and having access to the latest industry standard and proprietary CAE tools, are important aspects of Ricardo's brand attribute-led engineering approach.

For dynamics-related systems such as active steer, camber systems or proactive suspension, Ricardo can decide which technologies are most suitable for a given application, with predicted results measured against benchmarking data. Technology development projects can range from adding features to existing technologies such as lane-change assist to a steering system, through to creating an autonomous vehicle. For whole vehicle projects, Ricardo has broad-ranging experience, from benchmarking through to validation on vehicle types ranging from niche performance products to mass-market model year refreshes.

The company's dynamics expertise is just a part of the brand attribute engineering effort, which extends to performance and driveability, energy management, weight management, NVH, safety, all-terrain capability, and more. This breadth of capability – and the fact that it can be offered as an integrated and coordinated engineering effort rather than purely discrete specialist activities – enables comprehensive understanding and informed decisions of attribute trades and balancing during target setting, technology selection and vehicle development.

An expanding world

Intelligent benchmarking and target setting remain an ongoing process for Ricardo, as automotive markets develop and global competition increases. Customer expectations mature and evolve continuously, which means that the targets for yesterday's product will not be competitive with those of tomorrow's. Emerging markets are also introducing new requirements, with different driving styles, road conditions and customer expectations.

In addition to these market drivers, technologies enabling new levels of vehicle personalization, automation of driving tasks, and expansion of the performance envelope, each add to the dynamic engineering challenge.

All of these factors underscore the importance of Ricardo's brand attribute-led approach to engineering. No two vehicle brands can be considered alike – from the performance of the powertrain, the quality of sound and the feel of the dynamics.

To maintain its position as the engineering partner of choice for the world's leading auto makers, Ricardo aims to engineer the dynamics of its clients' products, such that each new vehicle conforms precisely to the brand character expectations of its consumers.

OEM Vehicle Dynamics By OEM Professionals

www.caymandynamics.com

For Further Information:
info@caymandynamics.com

Cayman Dynamics LLC
15201 Century Dr. Ste. 605, Dearborn, MI 48120
+001 734 657-5926 *(USA Eastern Time Zone)*

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Vehicle Dynamics Development | Testing | Training

Sense of freedom

DYTRAN'S NEW ANALOG 6DOF SENSOR HAS APPLICATION IN VEHICLE DYNAMICS AND RIDE AND HANDLING WORK, AMONG OTHER TASKS

Since its founding in 1980, Dytran has been engaged in the design and manufacture of piezoelectric sensing technologies, including dynamic accelerometers, pressure transducers and force sensors, to support a range of demanding customer applications and program requirements. Dytran sensors are used in a variety of automotive testing applications, such as noise, vibration and harshness (NVH); component durability; modal and structural analysis; squeak and rattle evaluation; road load data acquisition; transmission, powertrain and exhaust manifold testing; ride quality and durability; and whole body and hand-arm vibration measurements. In response to a growing number of customer requests for expanded offerings to support low-frequency vibration applications, Dytran has created a new analog 6DOF sensor, the model 7556A2.

The model 7556A2 is a fully analog 6DOF sensor containing a MEMS-based triaxial accelerometer, as well as three MEMS-based gyros. The sensor provides the end user x, y and z accelerations (*gs*) as well as rotational information (roll, pitch, yaw expressed in degrees/seconds) around three orthogonal axes.

ABOVE: **THE MODEL 7556A2 IS A FULLY ANALOG SIX DEGREE OF FREEDOM (6DOF) SENSOR CONTAINING A MEMS-BASED TRIAXIAL ACCELEROMETER AS WELL AS THREE MEMS-BASED GYROS**

The Series 7556AX sensor produces a single analog output per measurement channel. There are six measuring channels available for x, y, and z directions (acceleration along the axis and rotational rate around the axis). The sensor can be powered by any power supply that is capable of producing voltages from 5V DC to 30V DC with at least 12mA of current. All six outputs of the sensor are 'zero volts output for zero engineering units (EU) input', which means that when no acceleration or angular rate is present, the sensor outputs no volts nominally (some minimal offset is present due to the analog component tolerances, but that is precisely measured and reported on the calibration certificate). The voltage output from the sensor depends on the measure and can swing around 0V as high as +/-1.2V.

A unique feature of the 7556A2 is that it has been designed to have zero volts output for zero EU nominal input, eliminating the DC offsets typically found in many sensors of this type.

The sensor comes in a compact, hermetically sealed titanium package that is lightweight and rugged for survival in harsh environments. The sensor features a removable cable for convenience during installation and for removal from the test article.

Uses for the 7556A2 include – but are not limited to – the following test applications: vehicle dynamics, ride/handling, rollover, automotive safety, aerospace testing, large machinery including industrial off-road, aircraft flight dynamics, aircraft ground test, helicopter evaluation, amusement ride, playground surface investigation.

Dytran has built a solid industry reputation for its field-proven experience in the design and manufacture of sensors for dynamic testing. Today, Dytran is adapting new sensor technologies to broaden its product lines and to better serve customers across the dynamic measurement spectrum.

Single axis and triaxial DC MEMS style accelerometers utilizing state-of-the-art variable capacitance accelerometer sensing elements, combined with the company's packaging expertise, are enabling a wave of new product development. Dytran's engineers, working together with customers to meet new sensing challenges, are generating innovative, reliable solutions for today's toughest applications.

Audi RS4 (B7)

IN THE 1990S, AUDI'S PERFORMANCE MODELS WERE OFTEN CONSIDERED DYNAMICALLY INFERIOR TO THEIR RIVALS'. THE B7 RS4 CHANGED ALL THAT...

BY JOHN O'BRIEN

Fast Audis of the mid- to late-1990s, such as the S2 and S4, had a reputation for being beautifully built but somewhat unengaging to drive. A tendency for them to understeer, combined with inert steering feel, meant that BMW's M models usually took prime position in media comparisons.

However, the launch of the second-generation Audi RS4 (built by quattro on the B7 A4 platform) in 2005 announced a fresh approach that would change opinions of fast Audis. The RS4 was launched as a sedan, featuring the third-generation quattro system, which was built around an asymmetric Torsen T-3 automatic torque-biasing central differential and two open differentials, front and rear. Audi stated that the standard 40:60 front/rear torque split would give a more neutral cornering response.

To further complement the driver's ability, a Bosch electronic stability program monitored each wheel's rotational speed and applied the brake if a wheel's speed exceeded that of the other wheel on the same axle. The Bosch system had a torque-biasing ratio of 4:1, which was more aggressive than the standard car's 2:1 ratio.

The car's braking performance was equally impressive, with two-piece 365mm cast iron discs and Brembo monoblock eight-piston calipers up front, and 324mm two-piece discs at the rear. Customers could also specify optional 380mm carbon fiber-reinforced silicon carbide discs, which were claimed to reduce unsprung mass by 50%.

To ensure the brakes were equally effective in all weathers, the Bosch stability system also featured 'disc wiping', which applied the brakes 'frequently, but momentarily' to keep the surfaces of the discs dry in wet conditions.

The suspension featured a hydraulic linkage between the diagonally opposed KW dampers to counteract pitch and roll, joined to lightweight magnesium and aluminum alloy multilink arms, front and rear. At the front, the four-arm setup had a 'virtual steering axis', while the rear had a trapezoidal arm and unequal length track control arms, matched with hollow anti-roll bars.

The RS4 sat some 30mm lower than the standard car, at just 1,415mm, and wider, with 37mm added to the front track and 47mm to the rear. The car was supplied in the UK and Japanese markets with 9x19in wheels and 255/35 ZR19 high-performance tires from Continental, Michelin or Pirelli, while north American customers were supplied with cars equipped with 8.5x18in wheels wrapped in 255/40R18 tires.

The electro-hydraulic steering system was supplied by ZF, with the speed-sensitive servotronic variable-assistance rack having an overall ratio of 13.1:1.

All this added up to a fast Audi that was finally a worthy rival to BMW's all-conquering M3.

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