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ANNUAL SHOWCASE 2012

Lexus GS

EXCLUSIVE: The chassis engineering behind the first Lexus designed for driver appeal

Tire testing
All the latest facilities and techniques

Active suspension
John Miles test drives ACOCAR

Mazda CX-5
SkyActiv chassis technology revealed

COVER STORY

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A NOTE FROM THE EDITOR

It stands to reason that a group of vehicles engineered by broadly the same group of people, operating under the same leadership, will feel and drive in a broadly similar way. I believe the 21st-century marketing-speak for this is now 'Brand DNA'...

Changing this inherent 'character' or 'personality' is a tricky – and risky – business. Two of the most obvious examples of this in recent decades were Audi's gradual reinvention of itself as a 'premium brand' (both are VW Polos, but there's an ocean of difference between an Audi 50 and an A1), and Ford's Parry-Jones-inspired rebirth as a maker of driver's cars, starting with the original Ka.

Now Toyota and Lexus have decided that it's time to inject some on-road sparkle into their line-ups. For Toyota, the GT 86 coupe heralds a return to more dynamic vehicles reminiscent of the MR2 and Corolla AE86 of old.

For Lexus, this is uncharted water. But at least there has been recognition from within that build quality and refinement alone will never be enough to rival the German 'Big Three' – at least not on their home turf.

One of the many interesting articles in this issue is an insight into how Lexus has systematically redesigned the GS (and its new 'N' platform) to try to match the driver appeal of Mercedes-Benz and BMW (*p42*). Regardless of whether or not they succeed, full marks for giving it a go!

Graham Heeps

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CONTRIBUTORS

MATT DAVIS
Matt has recently driven such high-tech newcomers as the Mercedes C63 coupe Black Series and Porsche's '991' 911. So which of his recent drives are we most interested in hearing about? The Morgan 3 Wheeler, of course! (*p20*)

ADAM GAVINE
In Michigan to report on Automotive Testing Expo North America, Adam also took a trip to the Fowlerville proving ground to check out its impressive vehicle development facilities. His site visit starts on page 52

HENNING HOLZMANN
Henning kindly took a break from his day job as GM's global CAE lead for vehicle dynamics to co-author an article for *VDI*. Working together with Uwe Wurster of IPG Automotive, he describes GM's HIL simulation of closed-loop driving maneuvers (*p32*)

MATT JOY
For this issue, Matt interviewed TASS's Frank Litjens to hear his views on the emerging challenge of ADAS systems integration and future developments in the field of tire modeling. Turn to page 15 for more

PHIL MORSE
Phil follows up his exploration of shaker rig testing with a look at tire testing and modeling techniques (*p24*). Some 80 years after the first attempts at tire data acquisition, there's still work to be done before tire behavior can be truly understood...


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Reach for the Sky

THE CX-5 COMPACT SUV IS THE TORCHBEARER FOR THE LIGHTWEIGHT SKYACTIV ENGINEERING PACKAGE THAT'S CRUCIAL TO MAZDA'S FUTURE. BY **GRAHAM HEEPS**

Little in the way of all-new product has emerged from Mazda's Hiroshima engineering workshops recently, but there's a very good reason for that.

Ford had reduced its 33% stake in Mazda to 3.5% by the end of 2010. Newly independent of Blue Oval platform-sharing, and deciding to meet the low-weight, low-CO_2 challenge head-on, Mazda has put its faith in all-new SkyActiv Technology, the product of some five years of engineering across many disciplines.

The first model to embody the new powertrain, body, and chassis thinking is the 2012MY CX-5, Mazda's first C-segment SUV. Hideaki Tanaka, the car's program manager, explains that the vehicle engineering program itself began only in 2009, but that work on the SkyActiv Chassis elements embodied in the car have been in development since 2006.

"The biggest challenges were creating SkyActiv technology itself, and starting CX-5's development at the same time as SkyActiv was being developed," he says. "A major consideration was that we will be using this technology in other cars as well. In order for us to achieve that, the concept we used was Monotsukuri Innovation (see box, overleaf). This concept is based on separating within engineering all the parts that will stay common across all car lines in terms of their hardpoints, from the parts that will be variables."

Tanaka adds that SkyActiv Chassis offers the freedom to move hardpoints to suit the detail design of a specific vehicle.

"For CD-segment cars such as Mazda6, we might need a lower top mount for example. Or on a C-car such as Mazda3, we can change the track width. You then need to get the manufacturing of the hardpoints common. Such a big challenge justifies the all-new engineering. Mazda is a very small company so we're proud of such a breakthrough."

SPECIFICATIONS

Mazda CX-5

Dimensions: 4,540mm (L) x 1,840mm (W) x 1,670mm (H)

Wheelbase: 2,700mm

Track: 1,585mm (F), 1,590mm (R)

Ground clearance FWD/AWD: 215/210mm

Turning circle (curb to curb): 11.2m

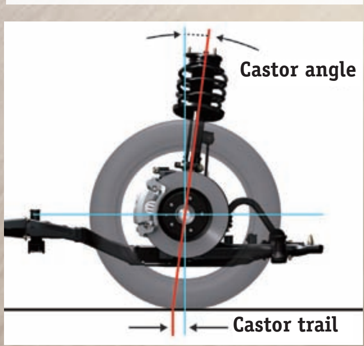
Front suspension: MacPherson struts with NHK springs and Showa dampers. ARB ø21mm

Rear suspension: Multilink with Mubea HZP springs and Hitachi dampers. ARB ø18mm (FWD) or ø19mm (AWD)

Wheels/tires: 17in x 7J with 225/65 or 19in x 7J with 225/55 R19

Steering: JTEKT column-type EPS. Ratio 15.5:1

Brakes: Front – Akebono, 297mm x 28mm ventilated front discs. Rear – Hitachi, 303mm x 10mm solid rear discs. Vacuum booster ø9in. Continental ABS/hydraulics



CASTOR ANGLE AND CASTOR TRAIL WERE INCREASED TO ENSURE FIRM STEERING AT HIGH SPEEDS

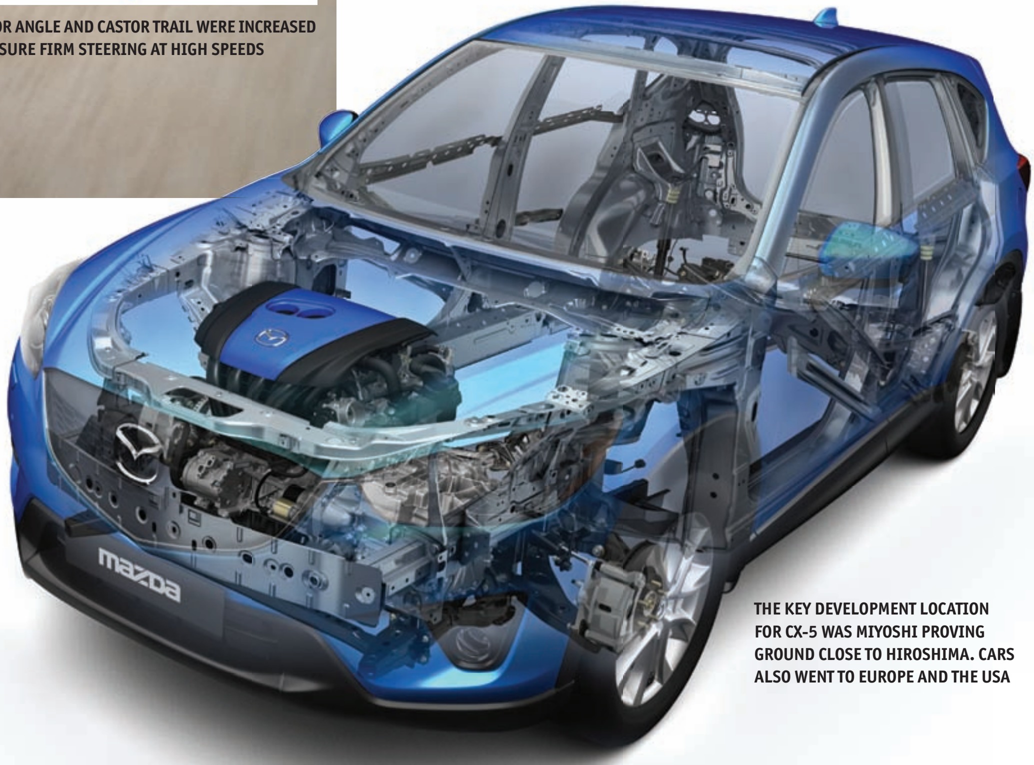
Balancing such a high level of common chassis architecture with the need for some vehicle-specific solutions inevitably resulted in a lot of toing-and-froing between Tanaka's vehicle engineering team and the chassis engineering team dedicated to SkyActiv (see *The Sky's The Limit* panel, overleaf).

"We had a lot of conversations and also a few battles," Tanaka laughs, "but we very much enjoyed the cooperation."

Draft specifications for SkyActiv-approved chassis components for the CX-5 were then handed to suppliers such as JTEKT, Akebono, and Hitachi to engineer and produce the required parts. Mazda stresses, however, that it retains the sole engineering leadership for SkyActiv.

With no predecessor model in the compact SUV segment to refer to, Tanaka's team benchmarked the key competition in the segment: Ford Kuga, Volkswagen Tiguan, Toyota RAV4, and Honda CR-V, plus contenders from Kia and Hyundai. Asked where he expects the car to be positioned in ride and handling terms compared to its rivals, he answers, "Our vision is very simple – to be the best. We wanted excellent steering and handling, but also ride comfort. We hope it'll be the new segment benchmark."

CX-5 FRONT AND REAR AXLES. THE SUBFRAME AND CROSS MEMBERS HAVE BEEN EXTENSIVELY REWORKED



THE KEY DEVELOPMENT LOCATION FOR CX-5 WAS MIYOSHI PROVING GROUND CLOSE TO HIROSHIMA. CARS ALSO WENT TO EUROPE AND THE USA

TO SMOOTH THE AIRFLOW UNDER THE CX-5, AIR IS DIRECTED UPWARD USING A NEW UNDERFLOOR DESIGN

The CX-5 will come in two states of chassis tune. The 'European' version, on summer tires, was tuned on roads around Mazda's Frankfurt development center, and will also go to Japan and Australia. Meanwhile the North American CX-5 has all-season tires and revisions to its EPS tuning, dampers, and some of its suspension bushings.

Adaptive suspension is not available in either version, however. Mazda has sought to get the passive suspension right first time, eliminating the need to employ variable damping: "We designed the optimum hardpoints right at the start, so we don't need an electrical device," says Tanaka, unequivocally.

MONOTSUKURI INNOVATION

In 2007, Mazda began reforming the processes involved in making cars, from R&D to manufacturing, under the philosophy of 'monotsukuri innovation'. Monotsukuri has been defined by one academic as the art, science, and craft of making things; in the Mazda context, it's about a common architecture concept and a flexible manufacturing concept based on bundled product planning. Mazda says that monotsukuri has led to standardization of parts for increased efficiency, enabling the company to deploy high-grade, high-performance technologies over a wider range of vehicle models. The resulting level of cost efficiency should benefit customers.

VDI SAYS

Mazda's recent 'zoom-zoom' mantra has been more about marketing messages than on-road reality, in our eyes. SkyActiv-Chassis is the opposite: interesting engineering that's truly worth shouting about.

The sky's the limit

SkyActiv Technology is Mazda's all-new, all-encompassing engineering philosophy for a more efficient, lightweight future. There are a number of streams to it, from new gasoline and diesel engines and transmissions, to body and chassis innovations.

For SkyActiv Chassis, a technology development group led by Tadanobu Yamamoto sought a combination of low- to medium-speed agility, balanced with ride comfort, and high-speed stability. At the same time, there had to be a simultaneous reduction in chassis weight and increase in rigidity. The result should be improved ride comfort and safety without sacrificing Mazda's 'fun-to-drive' philosophy.

In material published by Mazda, Yamamoto explains that engineers optimized the structure and engineering method of the suspension cross member to help achieve the weight reduction target. In the front, the center car section was extended and the longitudinal offset of the lower arm attachment position was reduced. In the rear, the longitudinal span of the cross member was extended and the longitudinal offset of the lateral link attachment position was reduced. Welding flanges were also removed to enhance the coupling rigidity of the welded sections. The structure adopted contributes to the 14% (for a CD-segment car) cut in chassis mass compared with current models.

SkyActiv-Chassis Technology aims	New front suspension	New multi-link rear suspension	Lightweight, highly rigid cross member	Electric power steering
1: Combination of light feel at low-mid range and stability at high speeds	●	●	–	●
2: Balance of ride comfort with light feel at low-mid range	●	●	–	–
3: Joint achievement of weight reduction and excellent rigidity	●	●	●	–

SKYACTIV-CHASSIS: MAIN TECHNOLOGIES USED AND THEIR CHARACTERISTICS

The revised cross member also helps improve handling. To avoid excessive yaw gain at high speeds, Yamamoto's team re-examined the rear suspension geometry. The links were optimized to ensure smooth movement at high speeds, and rear-wheel grip was increased in response to impact, reducing the yaw gain.

Mazda also adopted a higher steering gear ratio (15.5:1 on the CX-5). This simultaneously increased yaw gain at low to medium speeds, for greater agility, and reduced yaw gain at high speeds for better stability.

To ensure firm steering at high speeds, the front suspension castor angle and castor trail were increased. The EPS was then tuned to increase the assistance at low to medium speeds, making the steering lighter.

The next aim was to ensure that agile handling was properly balanced with ride comfort. To do it, Yamamoto's team revised the suspension structure to improve the handling without stiffening up the springs and dampers. To enhance the operational efficiency of the dampers, the mounts were set at a position that enables a greater lever ratio. This meant that the damping force and the rigidity of the top mount rubber could be reinforced, reducing the impact on ride comfort.

The rear suspension trailing link attachment position was also shifted upward. In this way, the direction of movement of the trailing links can be adjusted to more easily absorb longitudinal impact shocks from the road. As this also prevents the rear of the vehicle rising, the vehicle has increased stability under braking.

NEWS-IN-BRIEF

TRW is to open a new brake production facility in the state of Queretaro, Mexico. The 150,000ft^2 factory will make hydraulic control units for a variety of ESC systems, as well as brake actuation units, with production scheduled to begin near the end of the first quarter of 2012. It will employ around 450 people when fully up to speed.

bf1systems has pioneered a dual-gain intelligent amplifier for Formula 1. The new 'intelliamp' allows F1 teams to analyze dynamic loading and aero balance data from a single strain gauge installation on each pull- and push rod. The device was used for the first time during the Abu Dhabi young driver test in November 2011.

Michelin's new Primacy 3 car tire will be available in Europe from February 2012. Michelin says that, compared with its four market-leading competitors, the Primacy 3 delivers the best grip when braking on dry or wet surfaces and when cornering on wet roads. It engaged TÜV SÜD Automotive and IDIADA to conduct tests to support its claims.

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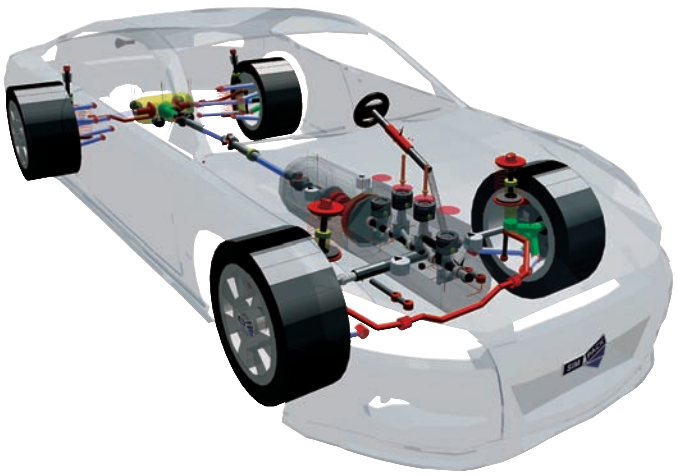

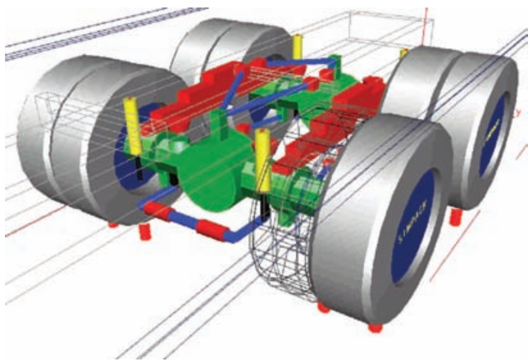

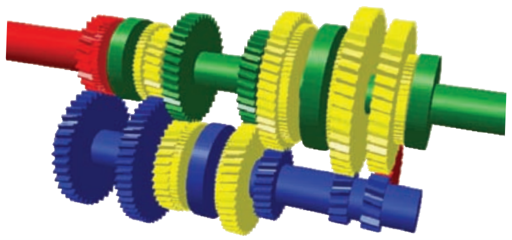

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i on the future

THE BMW I3 IS ONE OF THE MOST EXCITING NEW CARS CURRENTLY IN DEVELOPMENT. **GRAHAM HEEPS** GOT A SNEAK PREVIEW OF ITS UNUSUAL CHASSIS CONFIGURATION

BMW is not the only OEM working on a new range of electric vehicles, but the products it is readying for market look like being some of the most innovative around when they are launched in 2013.

The smaller of the two vehicles in development, i3, is a hatchback envisaged for city use and will be available either as a pure EV, or with an additional range-extender ICE.

Like its bigger brother, the i8, it will be notable for its pioneering use of weight-saving, structure-stiffening carbon-fiber reinforced plastic (CFRP) in the body-in-white module, dubbed 'Life'. That's married to an all-new, aluminum-dominated 'Drive' chassis, with a centrally located, underfloor battery pack and drive to the rear wheels from an electric motor sited above the rear axle together with its associated power electronics, transmission and differential.

As Christian Senger, chief engineer for project i at BMW, makes clear, the i3's platform shares little with its non-i cousins in the BMW and MINI ranges. In particular, the suspension architecture is all-new, and has been developed specifically for the i models.

"The concept of the i3 is optimized for an electric powertrain, which is quite different to a combustion engine system, and for this reason you won't find any suspension system component that is from any other vehicle we have," he says. "Brake systems and so on can be taken from existing components, but all of the links are special lightweight items for this vehicle.

"The i3 has a relatively simple front suspension system and an optimized five-link rear suspension for a lot of rear motor space that a normal car doesn't need. The links are very short and very wide, and only work with these huge, bespoke tires because we have a lot of space inside the wheels that you wouldn't get with a normal configuration. It gives us the width to be able to install an electric motor and a combustion engine in the rear, under the trunk floor. There isn't a normal suspension carrier under the rear of the car; it's just two vertical aluminum frames that carry the wheels. It makes it very simple to install different engines into the bay."

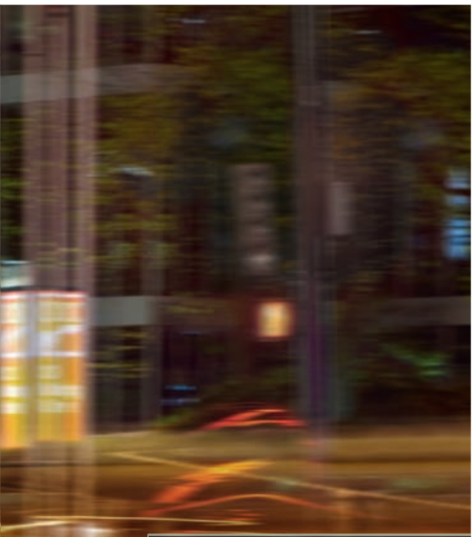
Senger adds that although this rear setup creates unusual geometry, it does not come with any major

NEWS-IN-BRIEF

It is with sadness that *VDI* reports the passing of motoring journalist Michael Scarlett. A former *Autocar* contemporary of John Miles, Michael later wrote for *VDI* and edited its sister title, *Tire Technology International*. His *Dynamic Legends* series for this magazine was a particular highlight, covering classic vehicles such as the Mini-Cooper, Citroën DS and Mercedes-Benz 300 SL. The staff at UKIP Media & Events Automotive Magazines would like to extend its sympathy to Michael's family and friends.

Nissan has produced the Juke-R concept, which squeezes the GT-R's drivetrain and suspension into the B-segment Juke crossover. The task was assigned to Nissan's Technology Centre for Europe in Cranfield, UK, working with race team RML, which built the Micra R concept back in 2003.

The wraps have come off BMW's 2012MY 3 Series. Compared with its predecessor, the new sedan has a wider track, increased length and wheelbase, but weighs some 40kg less. Ride comfort is said to be "taken to a new level", partly through the increased use of light-alloy components in the suspension.



disadvantages – at least not that have been found to date – and he points out that BMW has plenty of experience with five-link rear suspensions. The difference in acoustic behavior between an ICE drivetrain and a much smoother electric drivetrain mean that the NVH needs careful consideration, however.

"We get different [acoustic] forces on the links to the ones a normal suspension experiences. In terms of acoustics, you would normally have two elastic systems for NVH, but we have one elastic system in the links, which we can handle because of the aluminum subframe we are using."

He explains that the subframe is not as stiff as one might think, introducing some compliance to the system that helps reduce the need for extra rubber. The lightweight wheels and tires are also helpful in this regard.

"The combination of the stiff carbon structure and the aluminum subframe makes the vehicle great for urban driving," he claims. "It's not stiff like a normal BMW and it shows that a very simple suspension system can give good driving performance – most people are surprised at how well it works [when they first drive the prototypes]."

The i3's tires, which are being developed with Bridgestone and at least one other partner, are not of a conventional size.

"You won't find any other car with this kind of tire size – larger

SPECIFICATIONS

BMW i3

Dimensions: 3,845mm (L) x 2,011mm (W) x 1,537mm (H)

Wheelbase: 2,570mm

Curb weight: 1,250kg

Electric motor: permanently excited hybrid synchronous motor. 125kW/250Nm

Top speed: 150km/h (93mph)

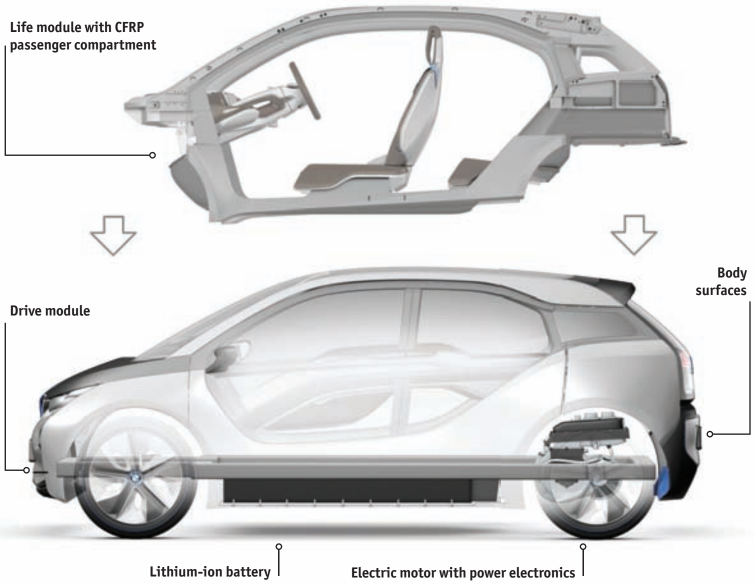
Acceleration 0-100km/h (62mph): 7.9 sec

Acceleration 80-120km/h (50-75mph): 6.0 sec

Everyday range: 130-160km (80-100 miles)

FTP72 cycle: 225km (140 miles)

Charge time: standard 6hr for 100% charge, optional 1hr for 80% charge



SEVERAL HUNDRED ENGINEERS ARE WORKING ON THE I3'S DEVELOPMENT, MORE THAN 100 OF THEM ON THE CARBON-FIBER BODY-IN-WHITE ALONE. 'COACH' DOORS GIVE GOOD ACCESS

NEWS-IN-BRIEF

EQT III has agreed to sell VTI Technologies Oy to electronic components company Murata Manufacturing Co Ltd of Japan. Since 2002, VTI has increased its sales by more than 75%, reaching a record high turnover of €75.8 million in 2010. Subject to approvals from competition authorities, the deal should be completed in 2012.

Under Volvo's new SPA (Scalable Platform Architecture), several groups of cars will share the same basic chassis structure, seat frame, electrical system and driveline. "When the first [Volvo] SPA model is launched in a few years' time, about 90% of its components will be new and unique," says Peter Mertens, senior VP for R&D.

Dow Corning's Molykote D-708 anti-friction coating is helping a major brake Tier 1 to reduce noise from brake-pad clips. The dry-film lubricant has now been specified for several vehicle platforms. According to Matt Hagemeyer, a Dow Corning application engineer, one advantage of a dry lubricant is added brake-clip lubrication durability with high resistance to road contaminants and temperature extremes.

• *Foundation brakes, page 36*

NEWS-IN-BRIEF

Global braking and chassis systems specialist BWI Group has won new business worth €1 billion in the last year, attracting four major new customers since 2010. The Asia-Pacific region has generated around 30% of the bookings; BWI is investing there to support the growth, including in new production facilities in Beijing, China and northeast India.

The result of three years of R&D by Multimatic, the Dynamic Suspensions Energy Recovery Dampers (DSERD) will be used for the first time on the Lola-Drayson B12/69 EV. This 850-horsepower LMP is designed to demonstrate the potential of an EV by lapping circuits faster than current LMP1 diesels. DSERD converts road input energy into electricity that is stored in a capacitor for later use.

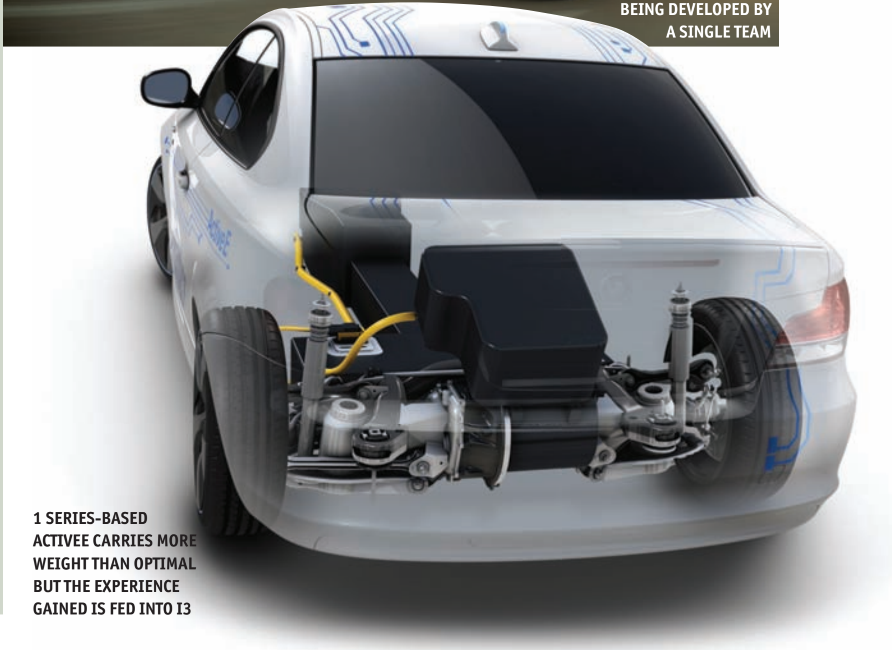
A new partnership between Maplesoft and VI-grade will see the integration of MapleSim models with the VI-CarRealTime framework. VI-CarRealTime has an open structure that allows for subsystems to be easily replaced by customized MapleSim models. Meanwhile MapleSim provides a multi-domain physical modeling environment that should allow VI-grade users to rapidly develop more detailed models than before.

WHAT IS I?

The BMW i brand comprises vehicles and services developed since 2007 as part of project i, a BMW Group think-tank set up to explore sustainable mobility solutions. Project i was charged with developing sustainable and pioneering mobility concepts. The intention of the initiative was to generate a transfer of expertise into future vehicle projects and the company as a whole.

The overriding goal of project i is to preserve the BMW Group's position as a leading supplier of premium products and services for personal mobility. To this end, the development engineers involved have always focused their attention on the entire value chain. As part of project i, the BMW Group is currently conducting field trials in everyday conditions with vehicles running purely on electric power: more than 600 MINI Es and a test fleet of more than 1,000 BMW ActiveE (1 Series) vehicles in the USA, Europe and China. Feedback from the customers trialling the MINI E and BMW ActiveE is being channelled directly into the series development of the BMW i vehicles.

I8 AND I3 ARE BEING DEVELOPED BY A SINGLE TEAM



1 SERIES-BASED ACTIVEE CARRIES MORE WEIGHT THAN OPTIMAL BUT THE EXPERIENCE GAINED IS FED INTO I3

and narrower than normal, with very low rolling resistance, made specially for us," says Senger. "This is our way of giving the vehicle very short overhangs. The vehicle doesn't look as high because there is a good proportion between tire diameter and vehicle size. And with narrower tires we are reducing the drag of the vehicle without reducing the contact patch between tire and street. That's the philosophy for BMW i because the less energy you need, the better."

That necessity for careful power management applies to the EPS, too. The hardware will appear on other BMW models too, but the geometry has been adapted to a rear-engined vehicle, with the opportunity that opens up for a tight turning circle.

"The crank angles are different so we have done a little optimization, that's all," says Senger. "We have lower weight in the front and optimized tires, so we have one of the lowest steering forces of any BMW. The steering system is based on 12V. It's a limited energy source and we want to avoid installing a big 12V battery that you don't need to start an engine. As a result we are working very precisely on how much energy each electric component needs, and the peaks of demand: for the braking system, steering system, AC evacuation pumps, etc. We are trying to control the energy demands via a DC/DC converter, and there is also a cost and weight factor as to how big your DC/DC system is."

Senger says the i3's ride and handling will benefit from "the right genetics". Its battery mass is between the two axles, as low as possible, and the rear-mounted electric motor gives 50:50 weight distribution and good traction. The result is that the vehicle is reported to be naturally very stable, with very little roll (it is fitted with smaller ARBs than normal). "It means you can give it

DOOR PANEL MATERIALS INCLUDE NATURAL FIBERS

a soft suspension to make it very comfortable," he adds.

The mechanical design for the final i3 test vehicle fleet was due to have been finalized by the time this edition of *VDI* went to print. Many series production tools are already on order, notably the complex steel tools for the Life module's carbon-fiber.

"We need to be sure that we have complete control of the production process," stresses Senger. "Nobody has done this before, and BMW always delivers quality. For this reason there will be more physical prototypes than for a normal program – it's a new concept and they will have to do much more testing."

To help ensure that learnings are quickly transferred from one car to the other, the i3 and i8 share many key features – including the rear suspension design – as well as the same engineering team and many suppliers, too.

VDI SAYS

The EVs shown so far can be loosely split into two camps: those adapted from current models, and those new from the ground up. Of the latter group, the BMW i cars seem to be the most radical of all. We can't wait.

tedrive Steering
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MECHANICAL LIGHT WEIGHT STEERING GEAR

tedrive Steering is revolutionising mechanical steering technologies with an innovative lightweight mechanical steering solution. The new mechanical steering concept features a two-piece steel housing and lightweight inner joints. With a total weight of 3.6 kg for a compact car steering system, the lightweight concept saves up to 30 % in weight compared to conventional mechanical steering system designs.

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NEWS-IN-BRIEF

dSPACE has acquired a technology license for a platform for data management and collaboration from Systemite AB, Gothenburg, Sweden. This platform will enable dSPACE to offer embedded systems developers a solution for managing high volumes of data and models, as well as their dependencies, versions and variants.

Nexteer Automotive is to invest US$150 million in its Saginaw, Michigan operations. Long-term customer contracts through 2018, including General Motors' next-generation full-size pickup, are allowing Nexteer to upgrade and expand its testing and manufacturing capabilities, says the company.

Intercomp has introduced a new Coil-Over Spring Tester and Compressor. With a digitally measured travel of over 10.5in (267mm) and the ability to compress coil-over assemblies for service, the new design allows users to obtain test data over a greater travel range, while saving time.

What's Up?

VOLKSWAGEN'S NEW CITY CAR IS THE SMALLEST VEHICLE TO MAKE USE OF ITS NEW MQB TOOLKIT FOR TRANSVERSE-ENGINED, FRONT-WHEEL CARS. BY **GRAHAM HEEPS**

When Volkswagen first showed the Up concept car at the IAA in Frankfurt in 2007, it created a real stir. That was partly down to its cute styling, but also because of its unusual – for a 21st-century Volkswagen – rear-engine, rear-drive configuration.

Fast-forward to late 2011, and the production version of the Up is rolling off the line. And it's no surprise to learn that the car is built on a more familiar-looking front-engined, FWD chassis architecture. In fact, the switch was made way back in 2008, as Herbert Ruholl, technical project manager for Volkswagen's New Small Family (there will be other Up-related cars), explains.

"It was not only a question of cost, it was mainly a question of synergies with the other cars inside our new modular transverse toolkit [MQB – *Modularer Querbaukasten*, see *MQB ABC* box, opposite]," he says.

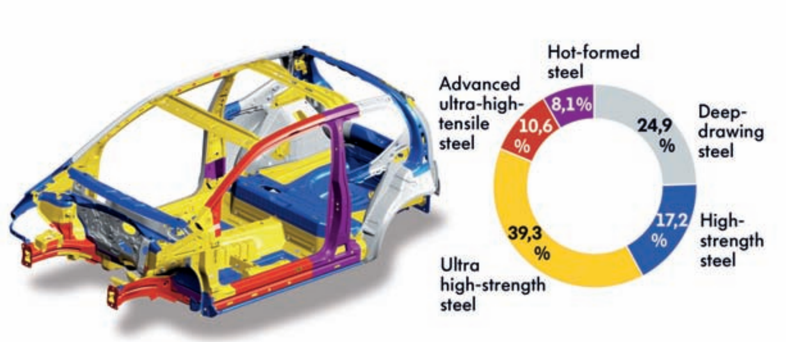
But keeping more or less to the concept car's wheel-at-each-corner silhouette, with its generous interior packaging, became the biggest headache for the project team following the switch to FWD. Some clever component location in the engine bay was required, particularly given the desire for excellent crash performance. The radiator, for example, has been sited to the left of center and further back, helping to decrease the front overhang to 585mm. Ruholl believes it is the shortest front overhang of any front-driven car in Europe. Meanwhile, a number of high-tensile steel elements are incorporated to protect the passenger compartment in the event of a frontal impact, a scenario in which major, non-deforming underhood components such as the engine, brake master cylinder and cooling system are designed to slide past one another to give a crush zone.

"It took us a long time to arrive at that solution with the limited width we have available [under the hood], particularly as we have left room for relatively large wheels," Ruholl explains. People apparently liked the original showcar's 18in rims, and although wheels that size will not be part of the line-up, tire/wheel combinations of 600mm in diameter will be, with a largest wheel size of 17in, the biggest in the class. He admits that this city car loses some steering angle as a result.

The suspension layout is standard, with the expected combination of MacPherson struts up front with a subframe made of 1.8mm-thick,

SPECIFICATIONS

Volkswagen Up (60PS)
Dimensions: 3,540mm (L) x 1,641mm (W) x 1,478mm (H)
Wheelbase: 2,420mm
Track width: 1,428mm (F), 1,424mm (R)
Unladen weight: 854kg
F/R weight distribution, unladen: 60/40
Springs/dampers: Mubea/Sachs-Boge
Front suspension geometry: camber 0.5°, toe-in 5', castor 24mm
Anti-roll bars: 18mm
Steering: NSK EPS, ratio 15:1, 2.9 turns lock to lock
Turning circle: 9.82m
Brakes: TRW ventilated, 256mm front discs and self-adjusting, 200mm rear drum brakes. 9in servo. Continental City Emergency Braking
Wheels/tires: 5J x 14, 165/70 R14 T (wheels up to 17in, tires up to 195 section width also available)



HIGH-STRENGTH STEELS SHOULD HELP SECURE THE UP AT LEAST FOUR STARS IN EURO NCAP TESTING

MQB ABC

Volkswagen's new MQB architecture will replace its existing transverse-engined, front-drive platforms as models come up for renewal. The architecture allows for different wheelbases and track widths, and standardizes the powertrain installation positions relative to the front axle, so that all powertrains are relatively easy to swap between the different vehicle classes. The Up's new 1-liter, three-cylinder petrol engine will also slot straight into the next Polo, for example, while a TSI turbo version of the same engine, first shown on the Up GT concept, could go into Polo and Golf.

MQB also gives the engineers options for further Up derivatives. The Bulli microbus concept shown at Geneva in 2011 got rave reviews, but a decision on how to make it had yet to be made at the time of writing.

"When we redesigned the Up in 2008, we weren't thinking about the Bulli. That only came later, in 2010, with the preparations for Geneva," says Herbert Ruholl. "Nothing has been finally decided. We have a definite desire to make this car a reality but we have in the MQB several possibilities: go smaller and keep it to the size of the Up, or bigger and take Polo as the basis. Several options are on the table as to how we could do it."

FOR UP BUYERS HAPPY TO LOSE SOME RIDE COMFORT, A 15MM-LOWER 'SPORT' CHASSIS IS AN OPTION

high-strength steel, and a twist-beam rear axle.

"The suspension kinematics of the front axle are very similar to that of the Polo, the twist-beam rear axle's too," says Ruholl. "We could even have taken the suspension struts and rear axle from the Polo – they would have fitted – but it wasn't done because the Polo components are made for a heavier car and therefore weigh more themselves and are more expensive. We even went as far as to develop new wheel bolts because they're lighter. We didn't want to make any compromises, lest we impact on the very low consumption figure of 4.2 liters/100km (67mpg)."

However, there are some carryover chassis parts in the Up's braking and steering systems. The TRW brakes essentially come from the Polo; Ruholl acknowledges that means they are slightly oversized, but there was no business case for a whole new braking system. The front discs were tweaked, however; the Polo disc's 256mm outer diameter and cross-section were not altered, but increasing the size of the ventilation channels helped reduce their mass by 1.5kg per vehicle. Continental's City Emergency Braking system is an option, and a first in this segment.

The EPS is a further development of the NSK system fitted to the Polo in India, and represents its first application in Europe. The European Polo still has an electrohydraulic system, but will get EPS in time, Ruholl assures, because it's a prerequisite for bringing driver assistance systems and park assist into the smaller segments. Up could also get park assist should the market demand it.

He describes the ride/handling balance as "a comfortable suspension but not too much roll. We were going down the comfort route but relatively late in the program, in 2011, we made it a bit sportier." The shift was prompted in part by comments from VW chairman Dr Martin Winterkorn during the final approval drives. Late changes to the anti-roll bars and damper tuning made the car a little stiffer, but Ruholl stresses that the launch versions of the Up are still a long way from GTI-stiff.

VDI SAYS

The Up is less quirky than some of its rivals, but clever packaging plus VW quality make it an appealing city car. We'd put money on the basic 1-liter model with small wheels being the nicest to drive...

MOTORSPORT-IN-BRIEF

ZF Sachs Race Engineering has made a new rotational damper available for LMP sportscars. This technology has been used in Formula 1 since 2003, but the simpler and cheaper new LMP version is made of aluminum rather than titanium. Its space-saving design could prove right for the times given the imminent proliferation of hybrid systems in LMP cars.

SKF is supplying angular contact ball bearings and thin-section bearings to the new Dallara DW12 IndyCar chassis. Incorporated into the wheel hub unit, the bearings are designed to maximize the rigidity and reliability of the entire wheel hub unit system and can resist lateral accelerations of up to 4g.

After its 2011 Italian Rally Championship success with the factory Peugeot team and driver Paolo Andreucci, EVOCorse's new QPS (Quick Pit Stop) wheels are to be made available to all customers for the 2012 season. EVOCorse claims that up to 30 seconds can be shaved from an emergency tire change using the QPS system.

In control

FRANK LITJENS FROM TASS TALKS TO **MATT JOY** ABOUT WHERE TIRE SIMULATION IS HEADING AND GIVES HIS VIEW ON THE FUTURE ROLE OF VEHICLE DYNAMICISTS

Sitting in a prime position on the curve of development in the latest active driver assistance systems (ADAS), Frank Litjens, director of sales and marketing at TASS, has the enviable ability to see what lies ahead in this fast-moving field.

The challenges for OEMs and engineers alike have already led to the formation of the Beyond Safe partnership, as Litjens explains: "TASS, TNO, and TTAI have joined forces recently and have communicated that to the market under the name Beyond Safe. It's designed to help the motor industry face the challenges that arise from increasing market demands: active safety systems and add-on safety systems as well as integrated safety systems in cars.

"The core activity of the Beyond Safe partnership is to bring physics into models, bring these models under control, and finally bring the control into the car," he continues. "In addition to software development, TASS is known for its worldwide network of offices, so part of our role in Beyond Safe is to offer the industry a single, local point of contact."

The streamlining of development processes is a crucial element in meeting market demands, according to Litjens. Lead times are the same or even shorter than before yet the expectations of the end user are continuing to mount, with even the most humble supermini benefiting from driver assistance engineering that was rare less than a decade ago. He sees this trend accelerating in the future: "More and more technologies are currently being embedded in vehicles, and these systems demand a great deal of knowledge, specifically around controls. OEMs and suppliers need to develop these skills and knowledge. You also see more and more items like cameras and radar coming onboard and inboard the vehicle. This is a more common thing and further integration of these individual safety systems will be an even greater challenge in the future.

"Development and implementation of these active and integrated systems, and their seamless and effective cooperation, adds to the overall complexity. So system control, I would say, is the key word in this game. This will increase the pressure on the OEMs but also on test institutes, such as Euro NCAP, to define these systems and protocols that they will need to make cars safer and prove it."

As well as a streamlined process for clients, the Beyond Safe partnership has some new tricks up its sleeve

ABOVE: **FRANK LITJENS, DIRECTOR, SALES AND MARKETING AT TASS**

LEFT: **VALIDATING THE DELFT-TYRE MODELS WITH REAL-WORLD TESTING**

"What we're talking here is something very different to what we have now"

THE BEYOND SAFE PARTNERSHIP OFFERS SERVICES, PRODUCTS, AND FACILITIES TO DEVELOP VEHICLE DYNAMICS CONTROL SYSTEMS

to reduce lead times and create even more accurate models. One of the most intriguing of these is the enhancement of the Delft-Tyre modeling software, as Litjens explains: "With the increasing complexity of vehicles due to the added systems, the importance of computer-aided engineering in the development is always increasing. Delft-Tyre is already an efficient, company-wide toolchain for supplying the OEMs with tire information.

"It's an essential part of the development and sign-off of the vehicle dynamic control systems to test in snow and ice conditions, so for the short-term future we are developing a tire model that is capable of predicting the tire characteristics on these low-friction surfaces. The big development is the increased replacement of intensive real-life vehicle testing, and to provide an ability to run these types of tests in CAE throughout the year rather than in a narrow window in the winter periods.

"For the long-term future, and I think this is the first time we can talk about it, we are also developing an 'intelligent tire' that will run onboard the vehicle. Microsensors will be placed in the tire, and using vehicle tire models we'll be able to derive tire characteristics out of the set of signals. So the model is onboard. This information can then be used as input to the ADAS systems in order to optimize the performance and capabilities.

"What we're talking about here is something very different to what we have now: the tires themselves have sensors that feed information to the tire model onboard the car – real-time signal transportation – and that output is then directed to the ADAS system. So it will get not only information from sensors such as cameras and radar, but first-hand information from the road via the tires' sensors. We will be able to fine-tune ADAS performance even more than we could before."

Not alone anymore

With software rather than hardware taking the lead in most advanced safety systems, the traditional role of vehicle dynamicists and chassis engineers could be called into question. Litjens firmly believes this isn't the case, but has clear ideas about where they need to go next.

"In the past they have been separate departments with separate responsibilities for the car, but these departments have to come off their islands. They will need to operate more closely with their colleagues in other areas because we are moving toward high-level system integration. Their way of working, their paradigm, their tools will need to be aligned with those of their colleagues."

The integration will even extend to traffic management systems. "The vehicles will gradually take over driving tasks to support the driver," Litjens believes. "In the future, systems that control driving will also improve traffic flow and further increase safety. Currently most of the active-safety systems are standalone, but by integrating these systems, and using techniques such as state estimation, this can lead to more optimized performance for the whole system and the need for fewer chassis components.

"State estimation is a technique in which a certain state is calculated based on the input of fewer sensors that don't measure the movement directly. The accuracy of the state estimation technique needs to be checked and fine-tuned in the vehicle dynamic control when it is programmed. Although the chassis engineer today maybe focuses on the dynamic component, this shows how, in the future, their work will be more entangled with the safety-related technologies."

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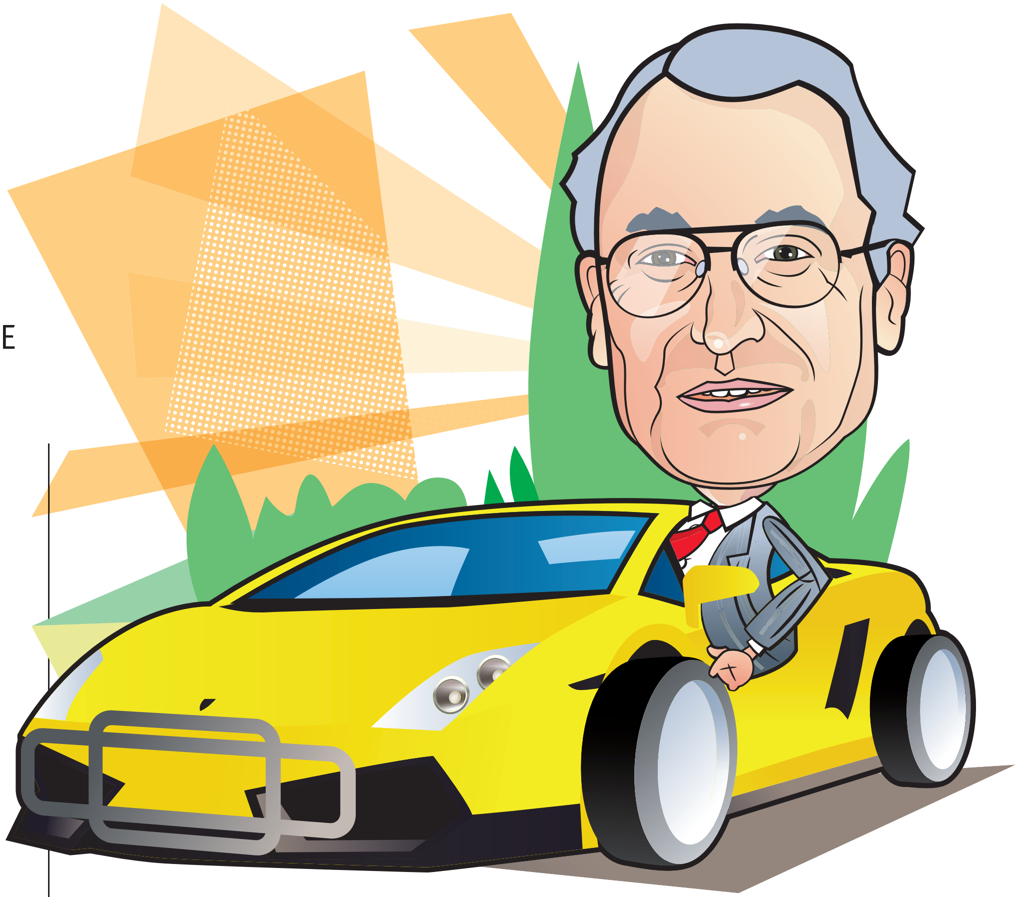
JOHN MILES ASKS: IS ALL-WHEEL DRIVE THE ONLY WAY TO GO FOR SUPERCARS?



Forty-four years ago, I had my first taste of four-wheel drive in the ill-fated Lotus 63 Formula 1 car (see *VDI*, November 2006). Four-wheel drive had worked brilliantly at Indy, where the stability gains gave confidence and high-speed balance, but for the precise, driver-dictated balance demands of European racetracks, it was a wash-out. Better tire technology had arrived, there was the additional mass, losses in the transmission, and the determined understeer that failed to respond to redistribution of drive-torque rearward. All played a part. At a wet Watkins Glen, Mario Andretti found to his cost that even with 87.5% of the DFV's drive torque going to the rear axle, a driveable 4x4 had just become a terrible two-wheel drive car.

Then in 1980, the Audi Quattro arrived on the scene. It too lacked driver-dictated balance, but its dead-stick stability could not have been more suited to everyday road conditions and all-weather mobility.

"In 20 years' time, road cars will either be front-wheel drive or four-wheel drive," declared chief chassis engineer, Jörg Bensinger. He was a decade out, but only because of the huge improvement in tire performance between times.

I suggest that the Bugatti Veyron and Lamborghini Aventador simply could not work safely without all-wheel drive, and from the same stable, the less powerful Gallardo, R8, and Bentleys are pussycats. It's simply no good having upward of 400bhp in a road car if the traction control is constantly cutting in. The Ferrari 458 Italia is an all-round jewel, apparently (much thanks to its E-Diff), but who in their right mind looks for a rear-axle slide on the road?

No surprise then that Ferrari now has a four-wheel drive platform, and Jaguar is planning one. Mercedes has done it before, and has sensibly retained strut front suspension, making the four-wheel drive system simpler and cheaper to package, with the additional advantages of better damping and ARB ratios, and top mount design.

Four-wheel drive dramatically stabilizes any car. "Boring to drive," complain the pundits. "No throttle adjustability or steering feedback," they say. Then we have Mitsubishi Evo-like, drive-torque-vectoring systems that can further 'perfect' cornering balance.

The counter view is that four driven wheels will inhibit you crashing your ludicrously fast, barely usable, technical marvel. For sure, the price to pay for a huge gain in security feel will be a lack of driver-dictated handling balance, as those of us who were involved in the F1 experiment found out. In my view, it's no bad thing, because anybody who says they regularly slide around corners, provoking power oversteer on the road, is either mad or a liar.

> "Anybody who says they regularly slide around corners, provoking power oversteer on the road, is either mad or a liar"

The point here is that I can't think of many road cars that are predictable in oversteer. Look at cars on the *Top Gear* test track and you will see them 'switching' from understeer to lurid tire smoking slides, confirming my own impression that a 'modulated' slide, as used to be possible in a Lotus Omega or Esprit S4S, is a rare event indeed, even on a test track.

I believe much of this controllability issue lies in the conflict between NVH isolation (usually lots of compliance) and production build tolerances on the one side, and on the other side the need for precise control of the rear suspension geometry. All of this drives manufacturers to err on the safe side and build in lots of understeer (toe-in kinematics) into rear-axle geometries, which in turn does not favor smooth rear-axle breakaway characteristics. With the additional stability that is inevitably conferred by four-wheel drive, there is at least the possibility of permitting more yaw gain from the rear axle, and therefore some gains in steering response, which limits handling predictability. Better ride comfort may also result from the shared drive forces, reducing the need for extreme 'antis'.

The idea that the 70mph or even 130km/h speed limits are actually observed by people in powerful cars is nonsense, judging from the number of BMW X5s and Range Rover Sports that belt past me on main roads. In these cases, four-wheel drive may save the owners from themselves, and for that we should be grateful, I suppose. In Germany, stability gains on a generally smooth and often limitless *Autobahn* will be felt most of all. Certainly, if you want to fully exploit the performance of the new breed of high-performance cars, then four-wheel drive is the only way to go. But for visceral thrills, forget it.

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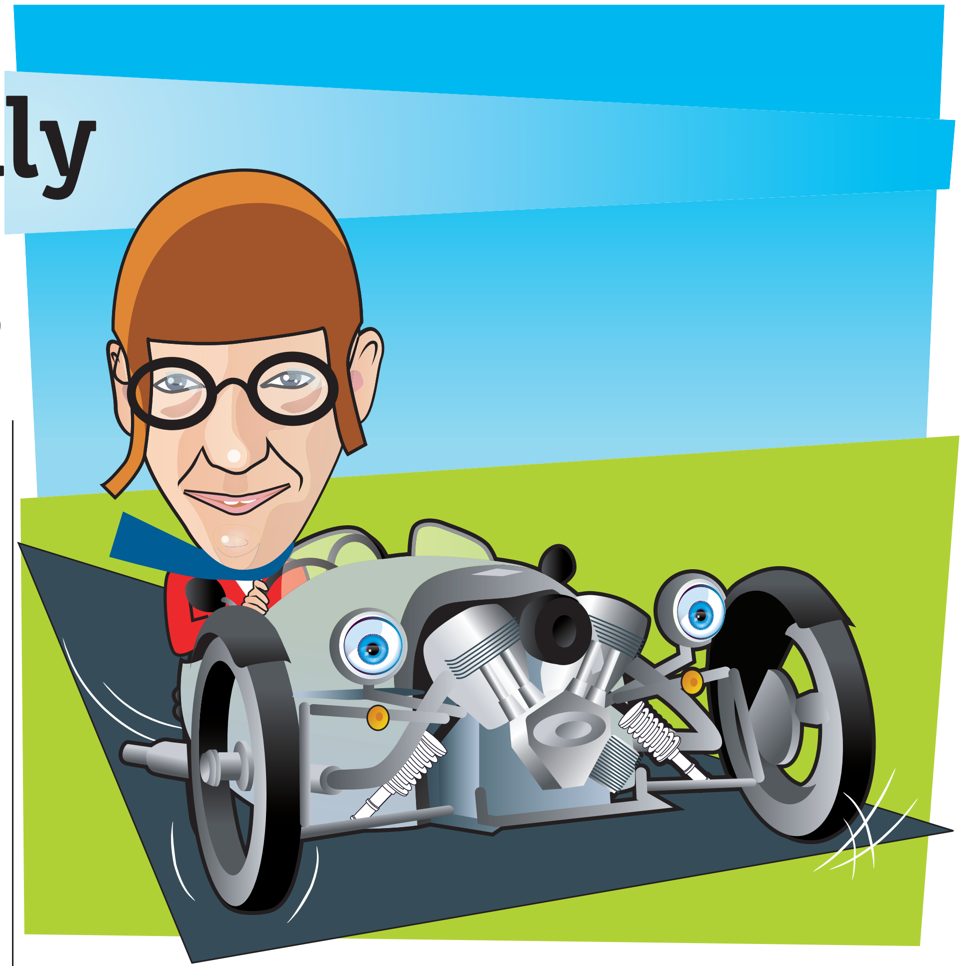


FORGET THE RED TAPE. **MATT DAVIS** LOVED MORGAN'S RETRO-RADICAL 3 WHEELER

Four wheels make a chassis automatically more stable and more popular with the public, whose purchases tend to keep the lights on at major companies. They do wonders for lap times, too.

Motorcycles, at the other end of the spectrum, sell in the relative dozens compared with the hundreds of thousands of car sales. Two-wheelers are more like a weekend jet ski to most potential buyers – of limited usefulness and not practical unless your goal is only to squirrel through packs of four-wheelers on the way across town to work and maybe save a little fuel. Four-wheeled transportation is a dire necessity.

So, how about trikes with just one two-wheeled axle to meet the passive upright stability part of the physics challenge? Where do three-wheelers fall in automotive evolution?

Ask Charles Morgan of the Morgan Motor Company Limited that question about now and he might just slug you in the kisser. No, he wouldn't, since he has always struck me as a worthy grandson to a Lord of the realm. But the rather surprising debate about whether the new-age 3 Wheeler classifies as a cyclecar or as a motortrike has come along to derail the Morgan delivery schedule, perhaps even destroying all hopes of any sales outside of Europe. I hope they fix this gummed-up situation, because I recently drove the new 3 Wheeler a lot in rain and dry, and it was a dynamic fun park urging my face to never lose its insect-covered grin.

See any archive pics of someone really hammering it through a curve in their pre-World War II F-type Morgan 3 Wheeler and that inside front wheel is up in the sky. The front axle was independent and only modified racing 3 Wheelers had dampers, the usual setup being simply "springy". In back, quarter-section elliptic leaf springs provided whatever cushion and road adherence was possible from the brackets hinged off the back of the gearbox. Though the front track was significantly wider than on the originals, the mid-last-century Morgan 3 also had a much longer wheelbase, so the dynamics sort of equaled those of the original and that inside wheel still rose up nicely in the curves, albeit now at higher speeds.

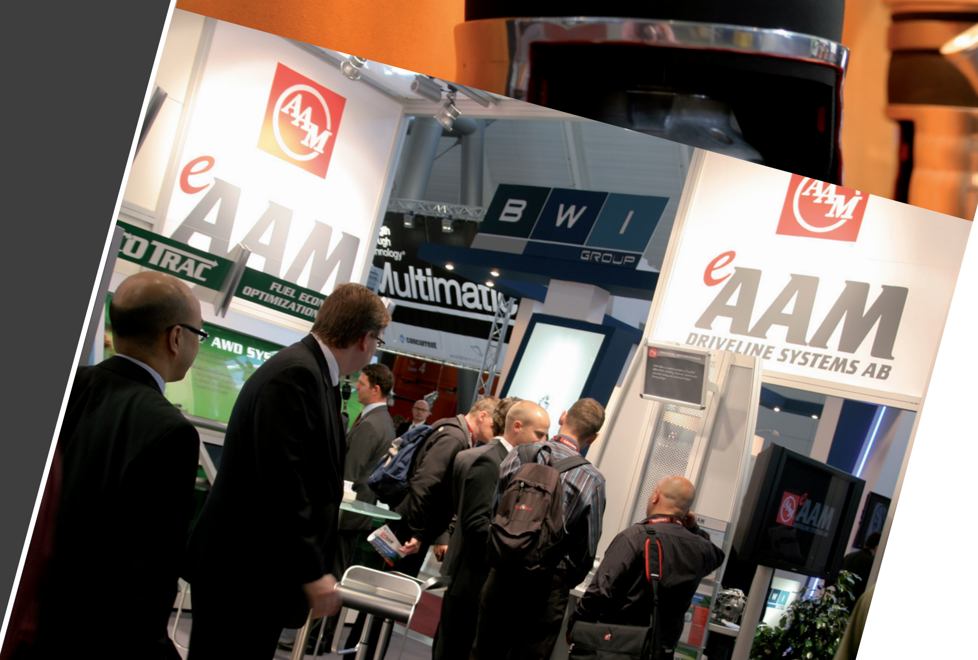
Part of that wheel-raising thrill comes from the sheer stiffness of the steel tubular framing wrapped in jig-hammered aluminum panels. This particular Morgan strategy is a first as seen on this new 3 Wheeler, but there is a similarly formed ashwood frame that follows the lines of the steel tubes. This structure at this dimension really could beat me up nicely if it weren't for the far more accommodating suspension approach. One of the other ways to smooth out the ride while also helping to dodge the rain squalls? Just go fast.

"I drove the new Morgan 3 Wheeler a lot in rain and dry, and it was a dynamic fun park urging my face to never lose its insect-covered grin"

Today's cyclecar has a much wider front track still, a Quaife steering rack, and beefy double wishbone suspension structure with standard monotube dampers, while in back the 16in wheel with Vredestein tire (there's only the one) is damped and sprung heartily on both sides as on any American two-wheeled "hog". There is now copious travel in back and the cornering from the front of the fuselage is go-kart steady. It would take one massive overload of lateral *g* to get an inside wheel and 19in Avon tire routinely way up off the ground. Forget about it.

In a straight line, the 3 Wheeler goes like stink, then it takes nothing at all to steer to wherever. After all is said and done, I have to admit that it feels like a sturdy reclining motortrike with body panels more so than it does any kind of car safe enough to co-mingle with the masses of sturdier and heavier four-wheelers on the road. If I were a governor of a region where the Morgan was for sale, I might poop on the party and order all drivers and passengers to wear helmets to complement the required rollbars; the mere chance of my constituents shaving off half their heads in gory accidents would not be a thing I'd want on mine.

But as compared with any previous three-wheeler certainly the latest Morgan 3 Wheeler is a paragon of safety and sophisticated driving dynamics. And compared with the legendarily god-awful Reliant Robin (a paragon only of having no road-going dynamics whatsoever), the new 3 Wheeler is a Ferrari FF.



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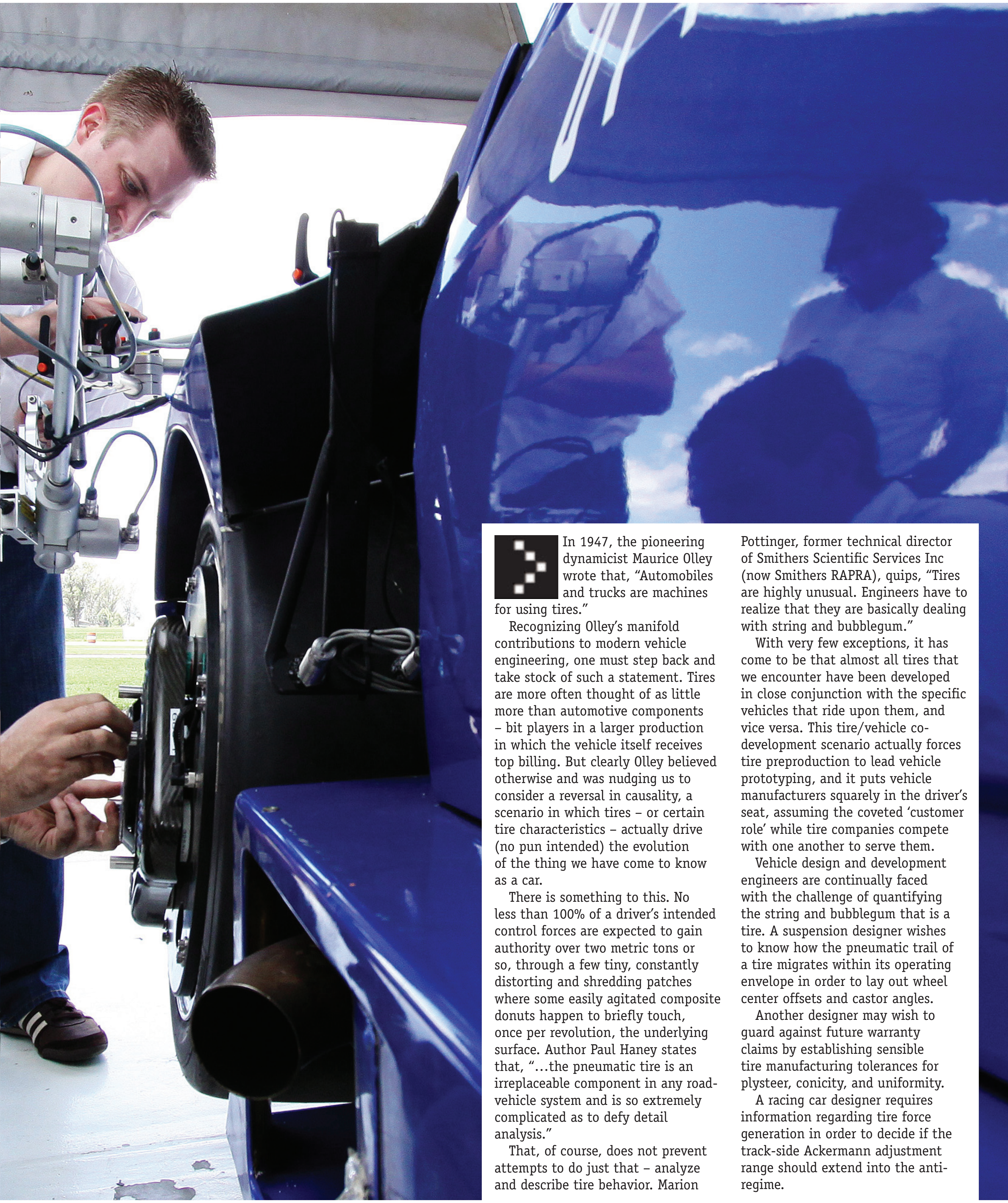
Model answers

PHIL MORSE EXPLORES THE ROLE OF TIRE DATA IN VEHICLE PERFORMANCE SIMULATIONS AND GETS THE LOWDOWN ON TWO IMPORTANT NEW TEST FACILITIES



In 1947, the pioneering dynamicist Maurice Olley wrote that, "Automobiles and trucks are machines for using tires."

Recognizing Olley's manifold contributions to modern vehicle engineering, one must step back and take stock of such a statement. Tires are more often thought of as little more than automotive components – bit players in a larger production in which the vehicle itself receives top billing. But clearly Olley believed otherwise and was nudging us to consider a reversal in causality, a scenario in which tires – or certain tire characteristics – actually drive (no pun intended) the evolution of the thing we have come to know as a car.

There is something to this. No less than 100% of a driver's intended control forces are expected to gain authority over two metric tons or so, through a few tiny, constantly distorting and shredding patches where some easily agitated composite donuts happen to briefly touch, once per revolution, the underlying surface. Author Paul Haney states that, "...the pneumatic tire is an irreplaceable component in any road-vehicle system and is so extremely complicated as to defy detail analysis."

That, of course, does not prevent attempts to do just that – analyze and describe tire behavior. Marion Pottinger, former technical director of Smithers Scientific Services Inc (now Smithers RAPRA), quips, "Tires are highly unusual. Engineers have to realize that they are basically dealing with string and bubblegum."

With very few exceptions, it has come to be that almost all tires that we encounter have been developed in close conjunction with the specific vehicles that ride upon them, and vice versa. This tire/vehicle co-development scenario actually forces tire preproduction to lead vehicle prototyping, and it puts vehicle manufacturers squarely in the driver's seat, assuming the coveted 'customer role' while tire companies compete with one another to serve them.

Vehicle design and development engineers are continually faced with the challenge of quantifying the string and bubblegum that is a tire. A suspension designer wishes to know how the pneumatic trail of a tire migrates within its operating envelope in order to lay out wheel center offsets and castor angles.

Another designer may wish to guard against future warranty claims by establishing sensible tire manufacturing tolerances for plysteer, conicity, and uniformity.

A racing car designer requires information regarding tire force generation in order to decide if the track-side Ackermann adjustment range should extend into the anti-regime.

Development engineers must have reasonable mathematical representations of tire characteristics in order to feed their requisite vehicle physics models and human-and-hardware-in-the-loop (H^2IL) driving simulators.

If one steps back to view the big picture, the current paradigm holds that full-blown virtual proving ground (VPG) models can be developed well in advance of physical prototyping. In addition, most vehicle subsystem and control system specifications can be driven from purely simulated characteristics.

However, VPG models, if they are to be of any practical use, must include mathematical tire models that are derived from physical tire tests. This occurs because, fundamentally, cars are easier to model than tires. A corollary is this: it is not (yet) pragmatic to drive tire designs in reverse, building physical tires to meet the performance specifications derived purely from simulation studies. The complexity of tires is such that they must be physically built and tested before they can be partially understood. If this paradigm is accepted, it begs the question: What type of tire testing is required to support high-level vehicle dynamics simulations?

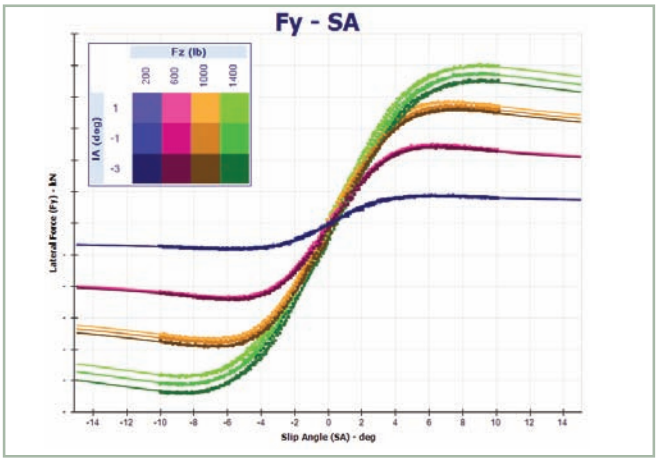
In the broadest sense, Doug Milliken of Milliken Research Associates (MRA) is correct when he comments, "Perhaps the best way to define tire testing is to categorize it into high-frequency and low-frequency characterization techniques." For passenger cars, these categorizations roughly relate to vehicle ride and handling, respectively. For racing vehicles, we might replace the term 'ride' with pitch control or aerodynamic platform control, but we are essentially talking about the same thing.

There are a number of widely used, industry-accepted modeling techniques, each requiring specific tire test protocols to support their derivation. Although all cannot be covered here, a few of the more popular techniques are described in brief in the sidebar (see *Popular tire models, p29*).

What might be immediately evident on reviewing them is the fact that there is no single model that proposes to comprehensively describe tire behavior for all operating conditions relevant to vehicle dynamics. It should also be mentioned that most existing tire models act to limit the fidelity of a vehicle dynamic simulation. As Mike Stackpole of Stackpole Engineering Services (SES) explains, "There is no question that predictive simulation [of tires] must improve. For now we make do with what we have. The Holy Grail would of course be to have a rolling FEA tire model that is also sensitive to surface variation and heat cycling and more – some sort of physical model that could do it all."

Short of that lofty goal, pieces of the puzzle do continue to fall into place. In developing full-vehicle dynamic simulations, SES has actually developed its own formulations of the Magic Formula. MRA continues to develop (in secrecy, in support of motorsport activities) the non-dimensional tire modeling

OPTIMUMG



A MAGIC FORMULA TIRE MODEL IS FIT TO TEST DATA FOR LATERAL FORCE VS. LATERAL SLIP AT VARIOUS VERTICAL LOADS AND INCLINATION ANGLES

CALSPAN TRANSPORTATION RESEARCH GROUP

CALSPAN'S TIRF OPENED IN 1973. THIS IS THE ORIGINAL FLAT ROADWAY TIRE TEST SYSTEM

HISTORICAL ADVANCES IN TIRE TESTING AND MODELING

1930s

1930: First tire data acquisition on paved road surfaces.
1931: First tire force and moment (F&M) measurements.
1936: First round drum versus flat surface F&M data comparisons.

1940s

1941: Earliest tire F&M models – for aircraft landing gear vibration analysis.
1949: Dunlop Universal Tyre-Testing Machine (UTTM).

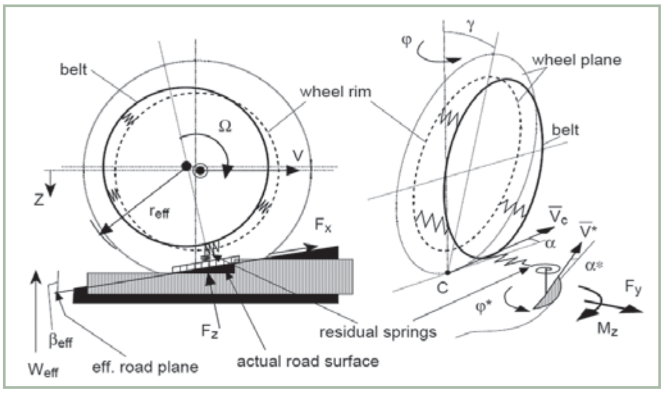
1950s

1951: Mathematical predictions of lateral stiffness and cornering forces from tire mechanical properties.
1954: Cornell Aeronautical Laboratory on-pavement, six-component tire tester for pneumatic tires; further developments in measuring F&M characteristics – including transients.
1956-1957: Major breakthroughs in tire performance and its relationship to vehicle stability and control.

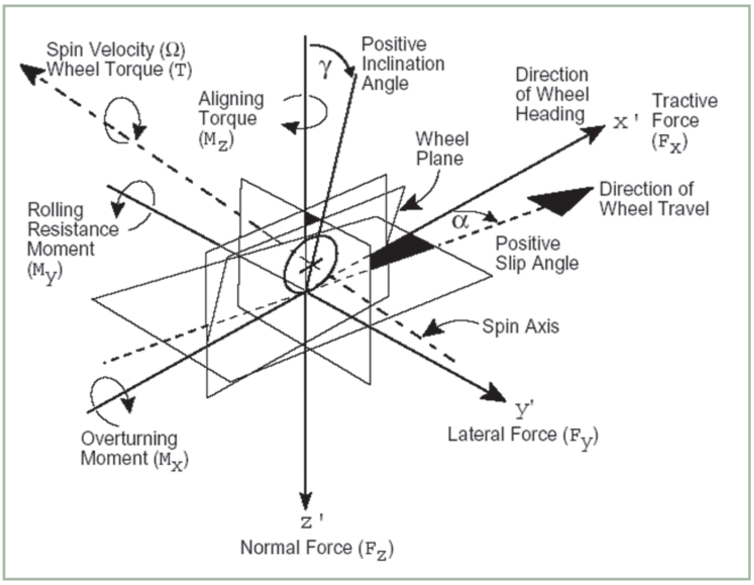
1960s

1960: TU-Delft Tyre Test Trailer (version 1). Earliest publication of non-dimensional tire modeling strategies.
1960-1965: Flat plank-type F&M machines go into service (Delft, GM, BF Goodrich, US Rubber, Uniroyal, etc.).
1962: BF Goodrich tire dynamics machine (drum).
1963: Experimental mobile tire testers (skid trailers) appear. Ford standardizes its internal laboratory tire force measurement procedures.
1965-1969: Low-speed uniformity measurements become factory-common.
1966: General Motors develops internal F&M specifications for its tires.
1967: Karlsruhe University of Technology develops internal drum test machine.
1968: Tethered vehicle + tire testing at Motor Industry Research Association. Multiple tire companies join forces to co-sponsor university research to develop analytical tire models.
1969: Pirelli proposes inverse procedures for matching tires to vehicles using mathematical models.

VEHICLE DYNAMICS SIMULATIONS, SUCH AS THIS SLALOM IN CARSIM, DEPEND ON ACCURATE TIRE DATA



SKETCH-UP OF THE SWIFT TIRE MODEL



SAE TIRE COORDINATE SYSTEM

methodologies that it introduced in the 1960s. Dufournier Technologies (DFT) has developed an entire suite of tire models (badged DT1-DT9) to provide advanced characterization of transient, wear, thermomechanical, and other key phenomena and is pushing its models toward real-time solution capability – a necessity for driving simulators.

In an interesting historical side note, Eric Schuch, manager of the Calspan Tire Research Facility (TIRF), confesses, "In the early days, everyone believed that Pacejka and other models would kill the need for tire testing. Here were these new ways to mathematically describe a tire. Of course, the exact opposite has happened. Tire models have created even more need for measured data." Indeed. Tire models require more than mere validation, they actually require a slew of specific tests and measurements to feed their very construction.

And although all vehicle manufacturers are hungry for tire measurements, only the world's largest are in a position to collect them themselves using multi-million dollar in-house tire testing machines. Others rely on data provided by tire manufacturers, or on for-hire tire testing providers, or on consulting houses that offer specialized tire testing services.

Some consultancies are able to serve as tire test coordinators at for-hire facilities, providing highly refined tire models as an end service. The need to closely monitor

MTS FLAT-TRAC FLAT-BELT TIRE TEST MACHINE. A ROBUST LOAD FRAME APPLIES LOADS AND ORIENTATIONS TO A TEST TIRE, WHICH ROLLS ALONG A FLAT, MOVING, ABRASIVE BELT

1970s

1970: UMTRI Truck Tire Flat-bed F&M Machine. Highway Safety Research Institute (USA) publishes its analysis of tire traction properties and their influence on vehicle dynamic performance.
1970-1975: High-speed uniformity measurement methods are advanced by BF Goodrich and Dunlop. UMTRI develops tire test trailer.
1972: GM Link Belt Machine designed for "routine tire F&M testing". GM also introduces its Tire Performance Criteria (TPC) Specification System.
1973: Calspan's TIRF indoor tire testing facility opens.
1976: Source of plysteer identified by Pottinger.

1980s

1980: MTS introduces the Flat-Trac I, a commercially available machine for indoor, flat-surface tire testing
1981-1984: Semi-anechoic chamber installations proliferate (to study tire/pavement noise).
1983: Honda/UMTRI motorcycle tire F&M dynamics machine.
1987: Magic Formula tire modeling method introduced by TU-Delft / Volvo research group.
1989: MTS Flat-Trac IIs enter service – allow industrial laboratory examination of data for simulating vehicle rollover.

1990s

1990: Tire thermography developments support endurance and high-speed studies.
1990-1995: Indoor wear testing and theory development.
1993: Michelin introduces a purely empirical modeling method using Magic Formula based functions – an approach that is re-absorbed by Delft Vehicle Dynamics Research Center (TU-Delft + TNO joint venture) resulting in the "Delft Tyre" model formulation.
1998: Investigations into tire dynamic responses to torque variations and road unevenness provide stimulus for early SWIFT and FTire model formulations.

2000s

2001: MTS Flat-Trac LTR (Light Truck + Racing) machine increases indoor tire testing envelopes in hopes of supporting FEA-based F&M model development.
2005: TNO Tyre Test Trailer (version 2).
2010: New ventures such as NTRC and Camber Ridge promise advances in tire testing methods...

tire testing in order to assist tire modeling is championed by Doug Milliken, who remarks, "Let's just say I find it very convenient to live near a facility like TIRF." Milliken also succinctly defines the required expertise to correctly model tires when he says, "There is a ton of experience required to make sense of tire test data and get good model fits. It takes many, many samples to create any representative tire model. All the collected raw data needs to be scrutinized, compressed. And a big part of that is being able to identify the [data] outliers, and know how to handle them."

A few consultancies are tackling tire testing head-on. OptimumG, maker of the OptimumT tire handling data visualization/modeling software tool, not only offers tire test coordination and model generation services, but also conducts research in on-car data acquisition/analysis techniques that support the extraction of tire data.

OptimumG's Henning Olsson remarks, "We have seen enough tire data now to realize that no two tire test machines are alike in terms of the data produced. Two machines equals two different results. We are now beginning to look at data collected from wheel force transducers and other on-car instrumentation to better understand what's happening under real conditions, on real surfaces."

This thread is evident in DFT's work as well. Arnaud Dufournier, the company's founder, goes so far as to say, "You simply cannot speak of tire testing without knowledge of the road surface." DFT's focus on tire/ground interaction is evident in its offerings – services such as suspension arm strain gauging for on-car tire F&M measurement, on-site tire testing using a skid trailer of its own design, road Roughness Measurement System (RMS) characterizations, and special tire model deployments. DFT is also keenly aware of the effects of thermal loads and transient conditions upon tire performance. Dufournier states, "We are now implementing strategies on our skid trailers that help us understand how tires behave when temperatures, loads, and angles are changing quickly."

The perceived limitations in the predictive capabilities of current tire models within vehicle simulations have become exaggerated in recent years, perhaps because vehicle simulation techniques have advanced at such a rapid rate. At the risk of over-simplifying, there are recognized shortcomings in the following key areas: tire/road surface interaction, thermal modeling, transient response modeling, physics-based parameterization and computation in real-time environments.

In the USA, these demands along with a direct response to regulation (upcoming requirements for ESC as standard equipment on all passenger vehicles, etc.) have created a certain momentum, and it seems that tire

DUFOURNIER TECHNOLOGIES

ABOVE: **ELEGANT AND PORTABLE TIRE TESTING SKID TRAILER DESIGNED BY DUFOURNIER TECHNOLOGIES TO CAPTURE TIRE/SURFACE INTERACTIONS AT VARIOUS PROVING GROUNDS AND RACETRACKS**

POPULAR TIRE MODELS

Magic Formula: Sometimes called the 'Pacejka Model' after one of its developers, Hans Pacejka (Egbert Bakker and Lars Nyborg were actually the lead authors in the paper that introduced this method). Called the 'Magic Formula' because there is no physical basis for the mathematical equations used to fit the general shape of tire data curves. Sufficient for vehicle handling simulations not exceeding ~8Hz on smooth surfaces.

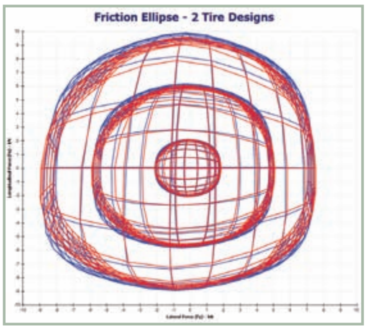
SWIFT (Short Wavelength Intermediate Frequency Tire): An extension of the Magic Formula methodology that can include rigid ring dynamics to describe the frequency response of a tire carcass and a road irregularity envelopment model for the tire contact patch. Used for vehicle ride simulations up to ~70Hz on arbitrary road surfaces.

FTire (Flexible Structure Tire Model): A physical, non-linear description of fundamental tire stiffness characteristics, valid up to ~120Hz. Used primarily for vehicle ride simulations and load path analysis simulations that relate to suspension and chassis component durability analysis.

Other models: These could include anything from static tire stiffness models, material damping characterizations, to FEA modeling that describes quasi-static load/deformation relationships.

RIGHT: **MULTIPLE TIRE TEMPERATURE SENSORS HAVE BEEN EMBEDDED DIRECTLY INTO THIS RACE TIRE CARCASS DURING CONSTRUCTION. TEMPERATURE MEASUREMENTS ARE TRANSMITTED WIRELESSLY TO THE VEHICLE'S DATA ACQUISITION SYSTEM, PROVIDING A VALUABLE LOOK AT THERMAL CYCLING**

THE INSTRUMENTED OPTIMUMG TOURING CAR LAPS THE CABALÉN ROAD COURSE IN ARGENTINA



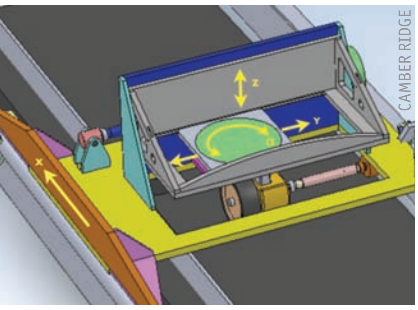
OPTIMUMG

LEFT: **COMBINED SLIP MEASUREMENT DATA FROM A LABORATORY TIRE TEST IS 'CURVE FITTED' WITHIN THE OPTIMUMT SOFTWARE TOOL USING THE MF-TIRE METHODOLOGY. THE RESULT IS A MATHEMATICAL REPRESENTATION OF THE TIRE'S FRICTION ELLIPSE SUITABLE FOR USE IN A VEHICLE HANDLING SIMULATION** testing is poised for a revolution to support these modeling needs. Two noteworthy projects were initiated several years ago and are now fully underway. The first, the National Tire Research Center (NTRC), plans to greatly expand the envelopes of current tire testing capabilities, while the second, Camber Ridge LLC, proposes to completely redefine tire characterization.

Frank Della Pia, executive director of NTRC, expects great advances in tire testing and modeling to follow the center's opening in January 2013. With the confidence of 30+ years of managing large-scale projects for General Motors, he declares, "We want to bridge the gap between the physical and virtual world, so we are installing a revolutionary test system that will be able to replicate any passenger car or light truck condition imposed upon a tire."

KH AUTOMOTIVE TECHNOLOGIES (CHANGCHUN)

CHINA'S AUTOMOTIVE INDUSTRY HAS UNDERGONE MASSIVE VEHICLE R&D GROWTH IN RECENT YEARS, AND MANY NEW TIRE TESTING MACHINES ARE BEING DEVELOPED TO SUPPORT THIS ACTIVITY



CAMBER RIDGE

TO BETTER QUANTIFY TIRE/SURFACE INTERACTIONS, CAMBER RIDGE PLANS TO TEST TIRES ON REAL PAVEMENT ALONG A 2KM PAVED OVAL TEST TRACK. LABORATORY-LIKE DYNAMIC CONTROL OF TIRE LOADS AND ORIENTATION IS ACHIEVED BY A CUSTOM-DESIGNED CARRIAGE ON A GUIDED RAIL

He is referring to the most technologically advanced version of MTS's Flat-Trac system to date, called the LTRe (Light Truck Racing, electric-drive), which was developed by merging MTS's extensive experience with flat-belt tire test systems with its compact, high-capacity, highly responsive electric drive systems that were originally developed for Formula 1 drivetrain testing.

Della Pia adds, "There will be nothing else like this in the world. Ten thousand Newton-meters of torque to the test wheel, delivered virtually on-demand. Slip angle sweeps at 90° per second up to 30°. We are finally going to be able to address all those things that have been on the minds of math modelers for years and years."

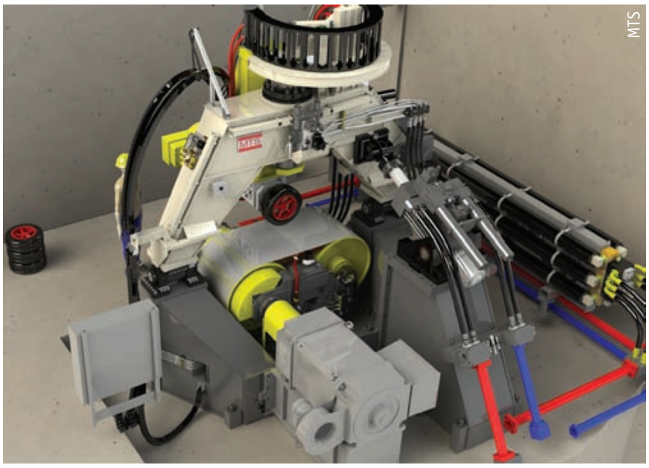
The approximately US$15 million NTRC project is funded primarily by General Motors, Virginia Polytechnic Institute and State University, and an economic stimulus package from the Virginia Tobacco Indemnification and Community Revitalization Commission. Della Pia makes it clear, however, that the facility will be open to all. He reports, "GM is a funding partner, not an operational partner. Its investment [reportedly US$5 million] is buying some dedicated test time during the first two years, but the facility is definitely open to other clients too." He quickly adds, as direct acknowledgement of Virginia Tech's planned involvement in the project, "We also plan to fold operating surplus into new technology and research activities."

Dr Jim Cuttino, an ex-Michelin engineer and former director of the North Carolina Motorsports and Automotive Research Center at UNC Charlotte, leads the Camber Ridge project, which has roughly the same cost and opening date targets as NTRC. With soft-spoken reserve he describes the plans as follows: "We intend to test tires directly on real road surfaces. We will accomplish this by combining the best of both worlds – the precision metrology of a tire test lab with the real-world test conditions of a skid trailer. Our test tire manipulator rides at high speed, in a controlled fashion, along a precision rail system – not unlike a rollercoaster – around a 2km oval, collecting data as it goes. The concept is such that the tire has no idea that it's not on a vehicle, so we're going as near to recreating real road conditions as we can possibly be."

This seems unconventional, to say the least, but Cuttino is confident and enthusiastic about the possibilities for advancing the state of the art in tire testing.

"Although it sounds quite radical, we are really just combining existing technologies in a new way," he continues. "The design specifications are being led by our affiliates, a group of nine automotive and tire companies that have a strong interest in pursuing this technology. They came to us and asked if we could provide tire models appropriate for vehicle simulators and advanced vehicle dynamics work. We think we can deliver."

MTS'S FLAT-TRAC LTRe (2012 VERSION) PROMISES TEST SPEEDS UP TO 320KM/H AND TIRE VERTICAL LOADS OF 30,000N. THE UNIQUE ALL-ELECTRIC DRIVE SYSTEM WILL PROVIDE UP TO 10,000NM OF TORQUE AT THE TEST WHEEL



MTS

Automobile companies can spend US$50 million per vehicle development to build physical prototypes and put them through their paces on various proving grounds, so it may not be that much of a stretch for them to view tire testing at a facility such as Camber Ridge as a long-term cost-saver.

When asked about the seeming loss of repeatability that might be introduced by testing tires on an outdoor paved surface, Cuttino remains undaunted. "This is not so different from what is being done now on proving grounds all around the world. The trick is to properly control the test tire loads and orientations, make high-quality measurements, and let the ambient conditions be what they may. Sure, there will be control conditions in place such as a concrete reference surface, an indoor rolling belt system – a number of ways to baseline the tires. But we actually like the idea of having measured tolerance bands on our tire data that account for temperature variation and surface variation and other variables. It just opens up so many possibilities for understanding tires better."

And so the circle is complete. We return to the big picture that is the need to better understand tires, knowing that a number of clever people are out there working very hard to make that happen. Marion Pottinger, a bastion of practicality regarding the hows and whys of tire testing, asks rhetorically, "Once you're able to model adequately for vehicle design, why go further?"

The answer may be that once that point is reached, there really will be no reason to go further. But it certainly seems that the co-dependent relationship between vehicles and tires may be one of the primary reasons that we have yet to arrive at 'the solution' after building and driving cars for some 120 years. This author, for one, is looking forward to the advances in tire understanding that are sure to unfold in the coming years.

King of the HIL

OPEL/VAUXHALL USES HIL SIMULATION OF CLOSED-LOOP DRIVING MANEUVERS TO DETERMINE HOW A NEW VEHICLE WILL HANDLE. BY **DR-ING. HENNING HOLZMANN** OF ADAM OPEL AG AND **DIPL.-ING. UWE WURSTER**, IPG AUTOMOTIVE GMBH

General Motors Europe (GME) Engineering uses simulation methods in the area of vehicle dynamics and chassis control to support and complement actual driving tests on the road.

The process is known internally as Road-Lab-Math (RLM). It is a combined development approach consisting of road, laboratory, and CAE activities to take advantage of the strengths of all three disciplines.

Hardware-in-the-Loop (HIL) simulation of an extensive catalog of driving maneuvers, plus the virtual reconstruction of complex real-use cases, are integral to GME's release process for chassis control systems such as ESC. Successfully passing the test catalog leads to a simulation-based release recommendation.

It therefore takes powerful simulation tools to simultaneously increase the efficiency of an automotive development process, reduce cost, and handle the growing number of variants. Probably the most fascinating part is using a simulation environment to model complex traffic scenarios that exactly match real conditions. This is particularly true if the simulation

LEFT: **TO EVALUATE THE PERFORMANCE OF THE SIMULATION, ACTUAL DRIVING TESTS WERE PERFORMED AT A TEST CENTER. THE TEST VEHICLE WAS AN OPEL/VAUXHALL INSIGNIA CDTI, SIMILAR TO THE ONE PICTURED HERE**

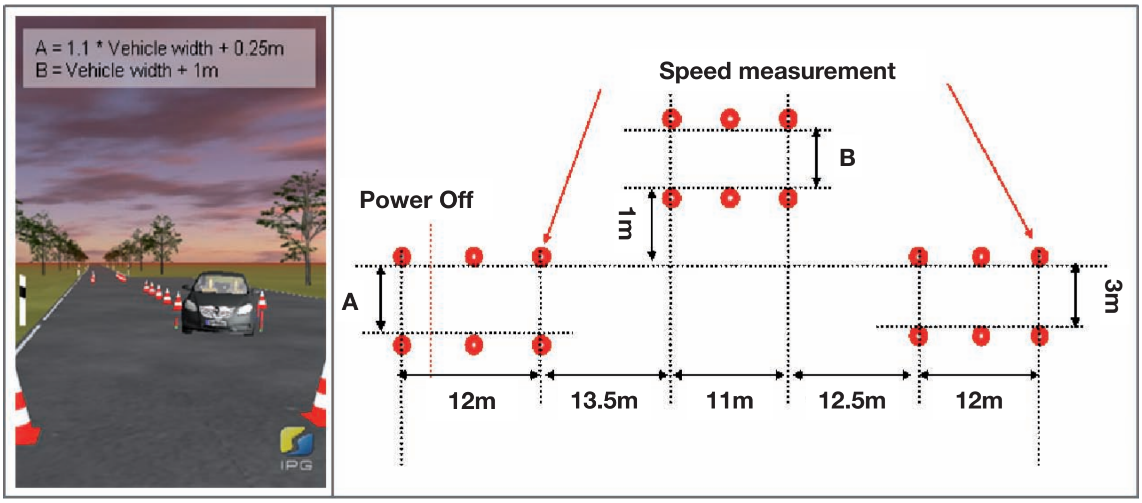
includes a realistic driver response to the simulated vehicle handling.

A noticeable part of GME's chassis control development, and especially the validation activities, is performed using HIL simulation test rigs. In other words, real ECUs (for example ABS/ESC) are coupled to a simulation model reflecting the vehicle dynamics behavior. Test maneuvers can be driven either closed-loop or open-loop, which means either with or without the interaction of a model simulating a human driver.

Closed-loop maneuvers are becoming more and more important because they offer the possibility to predict the results of vehicle performance tests. Long before the first prototype is on the track, the simulation will predict the handling scores of different driver types, ranging from professional to nervous. When this kind of knowledge is available early in the development process, it can be used for optimization measures at a point where the cost of changing things is still minimal.

For this reason, GME Engineering uses the IPG CarMaker/HIL real-time, high-end simulation environment.

FIGURE 1: **DURING THE VDA DOUBLE LANE CHANGE, THE VEHICLE IS STEERED ABRUPTLY FROM CONE ALLEY ONE INTO CONE ALLEY TWO, AND FINALLY INTO CONE ALLEY THREE**



EXAMPLE: EVASIVE LANE CHANGE

The respective test conditions and potential evaluation criteria for the evasive lane change maneuver in Figure 1 are:

- **Free rolling after throttle-off according to VDA definition (ISO 3888-2);**
- **Rapid steering to provoke ESC intervention and/or instability;**
- **Speed increase in 1-2km/h steps up to the limit.**

The boundary conditions are:

- **Small cones with baseplate, lane width is distance between cone baseplates;**
- **ESC is active and inactive (if switchable);**
- **Cone hit makes test invalid, slight cone shift is allowed;**
- **Objective evaluation of entrance and exit speed;**
- **Subjective evaluation of controllability, rollover stability, and steering effort.**

This can handle sophisticated closed-loop driving maneuver applications such as the VDA double lane change.

However, there is yet another reason why closed-loop virtual test drives are gaining popularity: leading automotive magazines, such as the German special interest publication *auto motor und sport*, use closed-loop maneuvers for their vehicle handling ratings.

To support this by simulation, the tools and the driver model need to be very precise. The IPG CarMaker/HIL environment, which GME Engineering uses for its chassis control HIL simulation, includes an advanced driver model. Named IPGDriver, it is claimed to be the most successful driver model for sophisticated closed-loop driving tasks, perfectly reproducing the actions and reactions of a real test driver up to the vehicle limits.

The VDA double lane change closed-loop driving maneuver provides a showcase example of a demanding handling performance simulation. The maneuver reveals how stable and controllable a vehicle handles during two abrupt lane changes (see Figure 1). Please refer to the panel above for the respective test conditions, potential evaluation criteria, and boundary conditions.

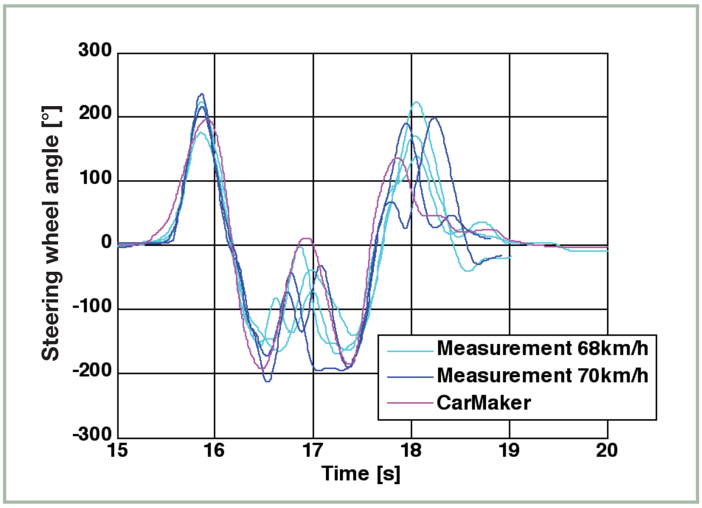
The results of this VDA test maneuver strongly depend on the individual test driver's strategy and experience: is he/she an eco driver, a sporty driver, an aggressive one, or a nervous driver with little practice? Each driving strategy will lead to different results – but the vehicle's onboard systems must cope with all of them equally well.

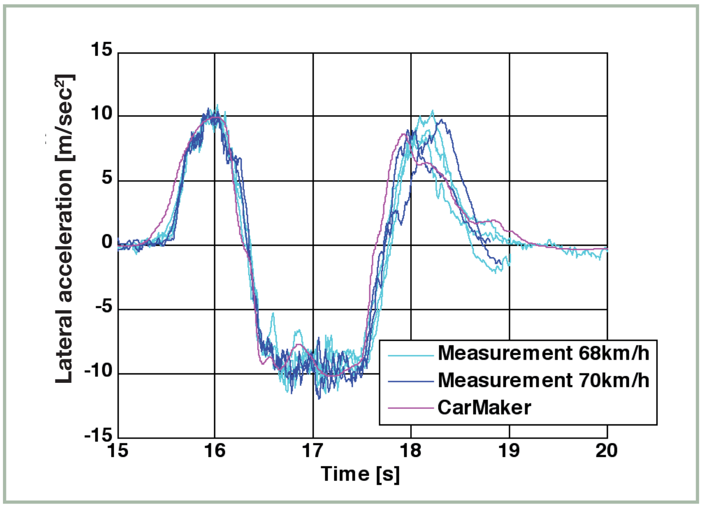
To conduct these tests either in reality or in simulation it is essential to know as much as possible about the maneuvers and their boundary conditions. Therefore, IPG sought an intensive dialogue with automotive journalists to understand how the maneuvers are performed by the test drivers, bearing in mind that they look at the vehicle from the car owner's perspective.

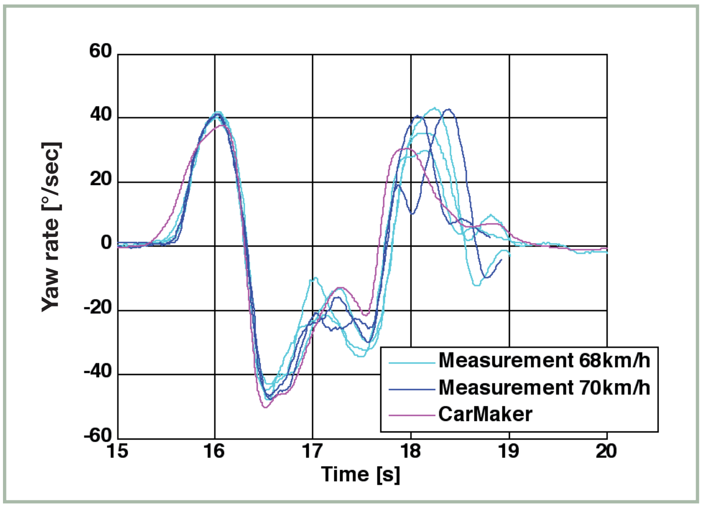
To evaluate the performance of the simulation, actual driving tests were performed at a test center. The test vehicle was an Opel/Vauxhall Insignia Sports Tourer 2.0 CDTI. In the test session, three different drivers were asked to perform the VDA lane change test with the highest possible entry speed, without hitting cones. Figure 2 shows the steering wheel angle during the maneuver at two different speeds. The drivers achieved slightly varying entry speeds (68 to 70km/h).

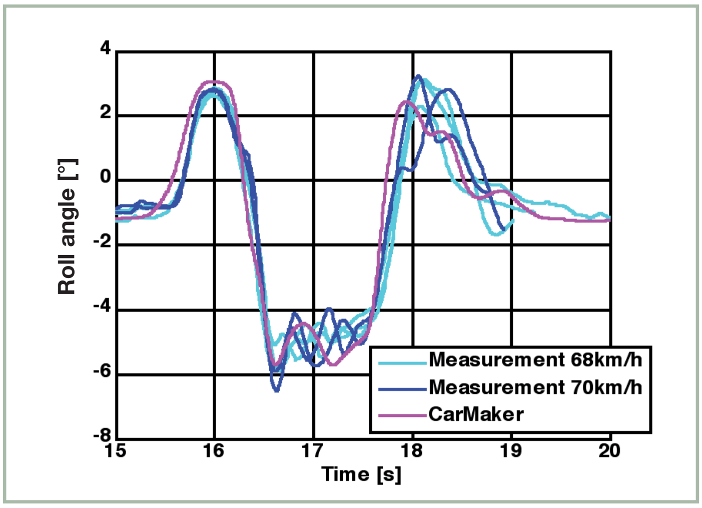
Initially, all drivers used nearly the same steering rate as well as the same maximum steering wheel angle at all entry speeds. In the simulation, the IPGDriver model exhibits a slightly lower steering rate than the real drivers when entering the first cone alley. However, the model applies roughly the same steering wheel angle. Later on (in cone alleys two and three), the real drivers obviously adapted their steering strategy to a feedback loop, resulting from ESC interactions. This resulted in a variety of possible steering wheel angle curves. Nevertheless, the closed-loop driver model performs this maneuver in nearly the same fashion as the real drivers.

Figure 3 shows the various lateral acceleration curves during the maneuver. Based on the lower steering rate of the IPGDriver at the start of the maneuver, the lateral acceleration differs slightly from the measured values. In cone alley two, the lateral acceleration of the simulated vehicle compares very well to the measured values with slightly more lateral jerk going from alley two to alley three. However, one always has to keep in mind that this is still a comparison in a closed-loop maneuver, where the driver model IPGDriver acts as a feedback controller in addition to the ESC system in the loop.









The yaw rate in Figure 4 is the essential vehicle state variable for judging stability enhancement systems. The characteristic humps (that is, the characteristics of this vehicle during the maneuver) are reproduced nearly exactly by the simulated maneuver. For completeness, Figure 5 shows the roll angle comparison between the measurements with the iNAV and the corresponding simulated values. In this case, the good correlation underlines the validity of the simulation results as well.

Although the simulation shows a slight difference to the test at the beginning of the maneuver, GME believes the results are convincing. The maximum entry speed in the simulation (70km/h) is the same as the maximum measured entry speed. Using the virtual driver model, IPGDriver for closed-loop driving maneuvers delivers results that are very close to real-world driving tests. The exact hit of an entrance speed of 70km/h in the VDA test shows the extraordinary precision of the simulation environment.

During the past few years, it was an important R&D goal to empower IPGDriver to reflect individual driving strategies. As a result of development efforts, the model now precisely simulates different driver reactions during different use cases. Even within sophisticated and demanding closed-loop scenarios, the complex driver/vehicle interactions of real tests are reflected in the model.

Why is this so important? Let's take ESC validation as an example. In a vehicle with a sensitive ESC setting, the differing steering strategies may or may not trigger the lane change pre-control. During an evasive lane change, this activation of the lane change pre-control algorithms can modify the handling performance, and can be interpreted by the driver as an erroneous system reaction. To avoid this and to prevent customer complaints, this situation must be detected in time.

It is part of a professional test driver's skillset to provoke exactly this erroneous system activation by imitating a driving behavior that is known to cause it. This gives the driver a chance to evaluate vehicle and controller response.

A fully functional driver model must be able to perform the same procedure. Only then can the model reduce the number of real-world tests and help to maximize the quality of results, while ensuring that they remain comparable and reproducible.

For GME, the bottom line is that the simulation tools are able to generate very accurate results in closed-loop driving test maneuvers. The results can even be used to predict a vehicle handling rating.

FIGURE 2 (TOP LEFT): **CHARACTERISTIC STEERING WHEEL ANGLE DURING VDA DOUBLE LANE CHANGE TEST AND SIMULATION**

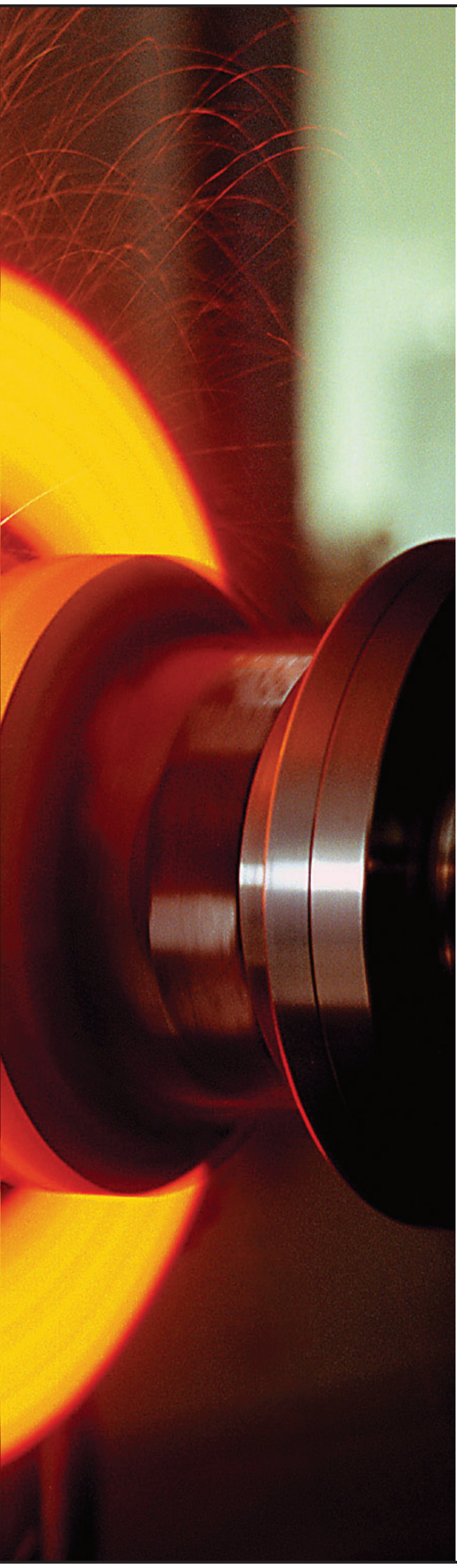
FIGURE 3 (TOP RIGHT): **CHARACTERISTIC LATERAL ACCELERATION PLOTTED DURING THE SAME TEST**

FIGURE 4 (ABOVE LEFT): **CHARACTERISTIC YAW RATE DURING VDA DOUBLE LANE CHANGE TEST AND SIMULATION**

FIGURE 5 (ABOVE RIGHT): **CHARACTERISTIC ROLL ANGLE PLOTTED DURING VDA TEST AND SIMULATION**

Stop press

OVERSHADOWED BY THE INNOVATIONS INVOLVING ELECTRONICS AND CAMERAS, THE EVOLUTION OF FOUNDATION BRAKE SYSTEMS IS A BALANCE OF ENVIRONMENTAL, SAFETY, COST, AND COMFORT CONSIDERATIONS. **GRAHAM HEEPS** INVESTIGATES



Brake-based vehicle safety has taken a quantum leap forward in the past decade. The now-standard stability control systems have become more sophisticated by the year, and have been supplemented by additional sensors and cameras to create intelligent cruise control, crash avoidance, and mitigation functions.

But traditional foundation brakes – typically steel discs and friction pads at the front, and discs or pads at the rear, powered by an engine-driven hydraulic system – continue to underpin the electronics. And on the face of it, a car's basic brake system looks much as it did a decade or two ago. With suppliers always under pressure from OEMs to reduce costs further, foundation brakes are a mature commodity product. But that hasn't stopped the Tier 1s innovating to lighten brake components and improve their performance.

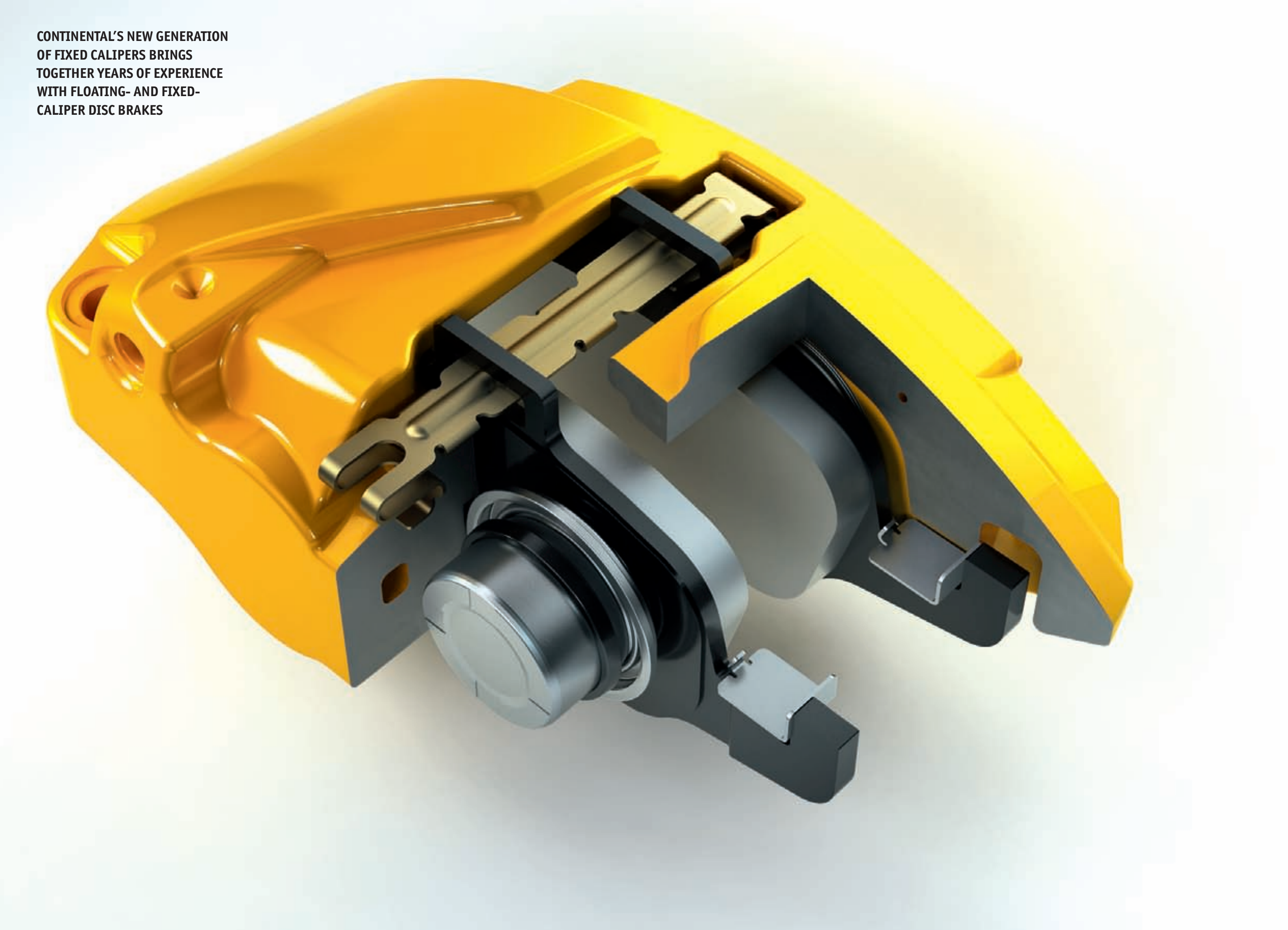
Continental's Chassis & Safety Division has recently unveiled its new 4MF aluminum fixed-type brake caliper. It's been developed over 12 months in response to the now-universal drive to save vehicle weight and therefore reduce fuel consumption and emissions. And with 1.5kg less mass than a comparable floating-type caliper, it's certainly achieved its primary goal. Conti has also transferred squeal-reduction techniques from its floating caliper design to the 4MF to ensure that there's no noise, vibration and harshness (NVH) penalty, a traditional fixed caliper weakness.

Best of all, the firm's engineers report that early testing – the part won't be on a production car before 2014 – promises a performance improvement, too. Hysteresis is bad news for rapid-fire ABS modulation, so the 4MF has been designed to minimize it.

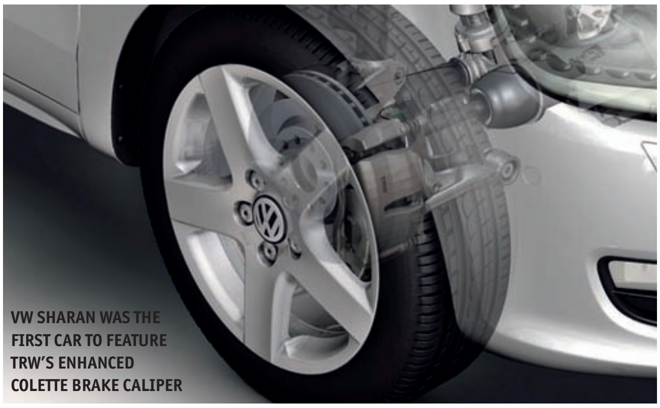
"We've applied some of the know-how on reducing hysteresis from our floating caliper to this fixed-type one," says Dietrich Golz (*pictured right*), head of development for wheel brakes at Conti's Hydraulic Brake Systems Business Unit. "We worked on the piston performance, and based on early tests with a car manufacturer, we think we may have gained half a meter [in stopping distance]."

"We've applied some of the know-how on reducing hysteresis from our floating caliper to this fixed-type one"
Dietrich Golz,
head of development for wheel brakes, Continental

LEFT: **REALISTIC BRAKING SITUATIONS ARE SIMULATED DURING BRAKE DEVELOPMENT**
RIGHT: **FOUR-PISTON CALIPER AND DISC FROM THE AUDI RS3**



CONTINENTAL'S NEW GENERATION OF FIXED CALIPERS BRINGS TOGETHER YEARS OF EXPERIENCE WITH FLOATING- AND FIXED-CALIPER DISC BRAKES

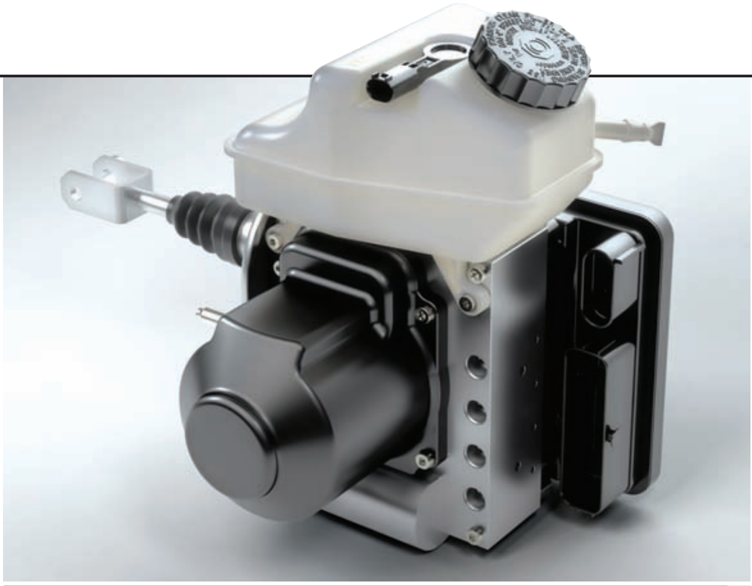


VW SHARAN WAS THE FIRST CAR TO FEATURE TRW'S ENHANCED COLETTE BRAKE CALIPER

Other developments are focused on maintaining current levels of brake performance while simultaneously meeting tougher environmental criteria. For example, friction material suppliers are working to remove copper from their pad formulations. On the back of water quality concerns, legislation is being rolled out in the USA that will limit the use of copper in pads to a maximum of 5% by model year 2021. Caliper makers, meanwhile, are working to reduce fuel-sapping residual drag.

"With classical foundation brakes you have residual drag of about 2-4Nm, which is equivalent to about 0.2L/100km of fuel," explains Manfred Meyer, technical director for braking, customer application and system engineering at TRW.

"To save that amount of fuel through engine development would require a lot of money. But if you give too much freedom to the brakes, so that you have zero residual drag, you get a disadvantage in pedal feel, wet braking performance, initial bite and stopping distance, because you



UNIVERSAL PANACEA?

Brake system architectures that do not depend on vacuum boosters and are more powerful than current systems are already in development.

One of the most attractive features of these electric motor-driven architectures is their energy efficiency. Not only is there less power consumption due to their on-demand nature, but with higher braking power available without a higher energy input from the driver, the brake system can potentially be downsized to save weight.

Continental recently unveiled its MK C1 (*picture above*), which gets higher brake system performance from fewer individual components. The brake actuation, the brake booster and the slip control system (ABS, ESC) are combined into a compact, weight-saving, electrohydraulic braking unit. Instead of the vacuum brake booster, the electric and hybrid-friendly MK C1 uses an electric motor that drives a cylinder piston in a linear way, combining the function of the brake booster during driver-initiated braking with the active pressure modulation of a slip control system. It's said to build up pressure faster than conventional hydraulic systems, making it well suited to rapid-fire ADAS requirements. In the event of system failure, a hydraulic fallback allows the driver to bring the vehicle to a stop with moderate pedal force. The new braking unit is currently in development for a series production debut planned for 2015.

TRW also has development ongoing in this area. The company's Manfred Meyer observes that such systems may yet remove the need to migrate carbon ceramic brake systems into the mainstream: "If you have a brake system that gives you a higher output power, then you don't need a base brake system that gives you higher braking power."

have too much clearance [between pad and disc]. It's a big challenge to reduce drag without impacting on other performance criteria."

TRW's solution comes as part of a package of improvements on the latest iteration of its ubiquitous Colette sliding caliper, called Premium Colette, which is due on a production vehicle in 2012. The caliper reduces the residual friction through more precise control of the sliding caliper's balance, by ensuring the pad is always aligned properly relative to the carrier, and by selectively employing a newly developed device to actively return the pad against the caliper body and piston. Together, the measures are said to reduce the residual drag to well below 1Nm, without compromising stopping performance.

Another area where engineers are keeping watch on maintaining performance levels is at the rear of the car, particularly on cars with the increasingly common electric parking brakes (EPBs).

"Electric parking brakes pose some challenges for friction pads," notes Frank Münchow, director of technology and innovation, Vehicle Safety and Protection, for Federal-Mogul.

"The piston that is used for an EPB in combination with the motor has a similar force every time; it's not like a normal handbrake, which often might only be put on halfway, or three-quarters on. So at the end of a hard journey with lots of handbrake applications, then you have a hot system. The pads swell with the high temperature, touching the cooler pistons, and the friction starts to go away. It means that you need much higher performance at the rear than in the past, both in terms of friction and temperature [resistance]. Especially if you're then parking on a hill."

Indeed, one might have thought that this question of sizing a brake system for optimum safety would be something that was done correctly on a routine basis. Not so, according to TRW's Meyer (*pictured right*).

"With foundation brakes you have a thermal capacity you have to install; if this is sufficient then you can't do more with the foundation brakes. But often we see that the thermal ability of the disc and the friction [pad] is not properly aligned, particularly in terms of its front/rear behavior. You must always have the right system sizing and balance between front and rear, and friction coefficient level compared with the thermal capacity of the disc and the system.

"We still see some OEMs not looking closely enough, or not having the right partner on the braking side, to have this properly set up. They may have a good front brake but not a good rear brake, or vice versa. They may have a good friction level, but not the right thermal capacity. Or they may have the right thermal capacity, but not the right cooling, the right aerodynamics underneath the car. You have to look at the overall system level, the

"It's a big challenge to reduce residual drag without impacting on other performance criteria"

Manfred Meyer, technical director for braking, TRW

FEDERAL-MOGUL'S NEW FRICTION FORMULATIONS ALLOW OEMS TO INTRODUCE LOW-COPPER AND COPPER-FREE BRAKE PADS WELL IN ADVANCE OF LEGISLATIVE DEMANDS

vehicle level, from the [initial] data calculation on the system architecture right up to the final vehicle release."

With the correct system sizing, thermal capacity and front/rear balance in place, the ABS system can then be sized properly too, and from there, all the modern must-have braking add-ons put in place.

One imagines that in the future, with OEMs keenly eyeing not only every centimeter of stopping distance, but also every gram of excess weight and joule of wasted energy in the foundation braking system, it'll be more important than ever to get these calculations correct.

After years of relative stability, there are likely to be noticeable changes to foundation brake hardware in the coming decades. In the drive for lower weight, we may see the proliferation of aluminum or carbon discs. In the pursuit of efficiency, particularly in the context of EVs and hybrids, we're likely to see more integrated, electric-motor-driven boosters rather than the traditional vacuum-style systems (see box, *previous page*). But however they look, foundation brakes will still underpin the sophisticated stopping systems of two decades' time, according to TRW's Meyer.

"Whatever you do on the electronics side, and even if you go to electromechanical braking, you will still need a foundation brake," he says. "Requirements such as CO_2 reduction and vehicle electrification are driving lower residual drag, weight reduction, and noise and comfort issues. That has to go along with stopping distance and stability, which is still a challenge. Plus all of these improvements have to be made with lower costs than we have today. That creates a demand for engineering, so that's what we're doing; if you stop improving your products, you'll be out of the market."

ELECTRIC PARKING BRAKE AND SWITCH FROM TRW. SUCH SYSTEMS INCREASE THE DEMANDS ON FRICTION PAD PERFORMANCE

An OEM's perspective

Audi has already announced the electrohydraulic combination brake for the forthcoming R8 e-tron. But what of the future prospects for more mainstream technologies – lightweight aluminum discs, perhaps?

"Their application depends on the vehicle concept and the required braking power," says Jan Münchhoff, head of development at Audi for foundation brakes and brake system design. "Aluminum brake discs tolerate a maximum temperature of 400°C (and then only aluminum MMC – particle-reinforced aluminum), which is approximately 40% of the figure for cast-iron brake discs, or 30% versus CSiC brake discs. An aluminum brake disc solution could be possible, for example, in a vehicle such as the Audi urban concept technology study (*below*), which combines less weight with relatively low speeds. Further issues to address include cost, abrasion and waste management."

With friction material suppliers already developing suitable pads for aluminum discs, it seems a production application (not necessarily an Audi) may not be too far off. Honeywell Friction Materials, for example, has shown a pad that includes an NAO (ceramic) friction material that forms a protective film on the aluminum disc.

At the other end of the temperature performance spectrum are carbon-ceramic brakes. Says Münchhoff: "Up to now they have been used on supercars such as the R8 or very sporty cars such as our RS models. Audi is committed to a top-down strategy in the premium class and the first shift from the D- to the C-segment will happen in 2012 with the introduction of the S6 and S7 Sportback models. A further expansion into the B-segment (in addition to B-segment RS models) is conceivable in the long-term, but a decision has not been made."

Could costs be reduced sufficiently for this to happen? "Ceramic brake discs would have to be standardized for all manufacturers," he warns. "The demand for CSiC is increasing, which will result in economies of scale for suppliers, which also helps to reduce costs. Nevertheless, the customer still has to be willing to pay for a premium product. This desire will be driven by factors such as light weight, high quality, design, durability and [less] brake dust."

As for more radical developments, he says: "Electrification of the car will bring with it side-effects, which might lead to new concepts due to the possibility of recuperative braking power. Hub motors and electromagnetic brakes in the wheel – whose potential is hard to predict – will require new braking concepts."

TOYOTA MOTOR EUROPE'S DIRECTOR, CS TECHNICAL DIVISION, **DUNCAN MCMATH**, DESCRIBES THE GENESIS OF THE N PLATFORM AND NEW CHASSIS ARCHITECTURE THAT WILL UNDERPIN THE 2012MY LEXUS GS AND FUTURE MID-SIZE PRODUCTS

Emotional rescue

SPECIFICATIONS

2012MY Lexus GS

Dimensions: 4,850mm (L) x 1,840mm (20mm wider) (W) x 1,455mm (H) (30mm higher)

Wheelbase: 2,850mm (unchanged but wheels moved forward 10mm)

Track: 1,575mm (F), 1,590mm (R)

Front suspension: High-mount upper-arm, double wishbones.

Rear suspension: Five-link

Steering: EPS. Overall ratio 13.2:1 (was 13.8:1)

Brakes (F Sport only): 18in, two-piece front brake

Wheels/tires: 17 x 7.5J-45 with 225/50R17 94W and 18 x 8.0J-45 with 235/45R18 94Y.
F Sport package: 19 x 8.0J-45 with 235/40R19 96Y (front) and 19 x 9.0J-60 with 265/35R19 94Y (rear)

For the new N platform and chassis, for which the new GS sedan is the first application, Lexus has made a clear decision to expand its appeal beyond its traditional strengths of refinement, smoothness, and ride comfort. While remaining true to the DNA of Lexus, our engineers have succeeded in adding agility, steering response, and body control to the mix.

Driving pleasure derives from a response that directly reflects the driver's intentions, like the movements of the driver's own hands and feet. To create the kind of drive that has this level of sensory resonance, the new GS development team aimed not only for high performance, but also looked to create an atmosphere in which drivers can relax and enjoy driving, from the improved seat and more adjustable steering column outward.

For driving to be enjoyable, there must be a feeling of unity between the steering and the vehicle. To achieve this in development, the team focused on good vehicle response to steering inputs, on vehicle attitude while cornering, and the level of rear stability.

In addition, to provide an atmosphere conducive to relaxed driving, the team paid attention to the traditional Lexus quietness and excellent ride quality, which meant concentrating on the feeling of quality from the off, and on vehicle movements that are unaffected by the road's surface irregularities or the magnitude of its undulations.

One example of that quality feel lies in the 53% reduction in suspension friction compared with the previous-generation GS, for smooth suspension movement and shock absorption from extremely low vehicle speeds. Another is in the revised suspension and bushing characteristics that contribute to what Lexus believes is the world's best shock reduction performance.

To achieve all this, the team started by completely updating the platform and newly developing the suspension. Then, the track was extended, the suspension geometry optimized, and the body rigidity and aerodynamics enhanced.

With these attributes as a foundation, the team proceeded to refine numerous items in support of the new GS's drive, including dramatic advances in various chassis control devices. This article will examine some of the key developments in more detail.

Work began on the N platform in 2004, with the first mules up and running before the current GS model, which sits on the older S platform, had even been launched.

The platform, which will also feature on future IS models, further evolves the high-rigidity body with additional spot welding, laser welding, and reinforcements. A substantial area around the redesigned rear subframe is now welded and glued. Vehicle performance was checked with every additional weld, the team repeatedly conducting actual vehicle evaluations to optimize weld spot distribution, helping to realize an unprecedented increase in rigidity. This degree of meticulous attention to structural detail helps to assure the stiffness required for accurate response to driver operations, contributing to a dramatic improvement in fundamental driving performance.

Much of the attention was focused on the rear of the car where, in combination with the rear suspension development that we will come to later, the new platform reduces lateral movement from mid-corner bumps.

The rear-floor side member, cross member, and other frame components have been optimally laid out, to assure substantial rigidity at the adhesion points of the rear subframe. Structural streamlining resulted in fewer parts, which in turn yielded less weight. Spec-for-spec, the new GS is about 40kg lighter than its predecessor.

Further structural measures help to achieve excellent handling stability throughout the car. The center floorpan sheet thickness has been increased, which benefits ride comfort and quietness. Numerous underfloor braces were optimized and a cowl side brace was adopted for the first time on a Lexus. The front subframe has been upgraded, enabling a 19in tire fitting on both 2WD and 4WD models.

The rigid new platform works with the GS's redesigned front and rear suspension to balance handling agility and stability with ride comfort, and to deliver drive quality and feel.

The newly developed, high-mount upper-arm, double-wishbone front suspension adopts aluminum suspension arms, new suspension geometry, and other structural revisions. These help to simultaneously achieve high measures of straight-line stability and ride comfort. Let's take each element in turn.

To achieve lighter weight and higher rigidity simultaneously, a newly developed front axle (hub bearing unit and steering knuckle) has been adopted on the 2WD model, contributing to enhanced handling stability and a further reduction in tire-road noise. A third-generation model bearing unit has been adopted whose outboard bearing pitch of center diameter has been enlarged with respect to the inboard bearing. The steering knuckle is in forged aluminum.

The result is a front axle whose camber stiffness has been increased by 26% with respect to the current model, for 3% less weight.

The less mass/higher rigidity trend continues with the forged aluminum front upper and lower arms.

Upper arm stiffness in the camber direction has been increased by 60% or more over the current model, along with a weight reduction of at least 23%. Meanwhile, the lower arm ratio (absorber and stabilizer) has been optimized for better kinematics and a 40% higher spring rate for the lower No. 1 bush enhances handling stability.

Changes to the lower No. 2 bush are extensive. The bush is larger, with a long, double orifice, and a new shape. A new-construction rubber

ADAPTIVE VARIABLE SUSPENSION

AVS controls damping force on all four wheels in response to driver operations and road surface conditions, helping to achieve high measures of ride comfort and handling stability. With the new GS, the specifications of rebound control and roll attitude control have been changed.

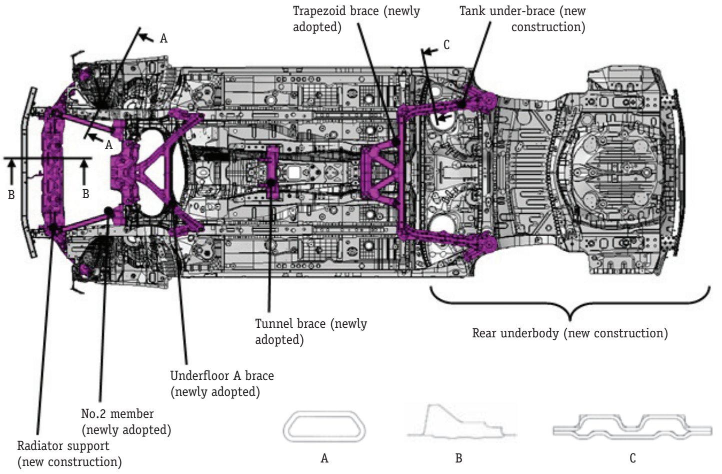
Based on signals from a vertical *g* sensor, oscillations are detected in heave, roll, and pitch due to inputs from the road surface. By controlling the damping force on all four wheels with non-linear H-infinity control logic to suppress oscillations in three directions, rebound is naturally smoothed down, helping to ensure excellent ride comfort.

With the control system previously employed, the four wheels were treated independently, and vehicle behavior in the direction of heave was controlled at each of the wheel positions. In contrast, the new system controls oscillation behavior at the four wheels simultaneously in a linked manner. This enables oscillation control, not only in the heave direction, but also in the directions of roll and pitch.

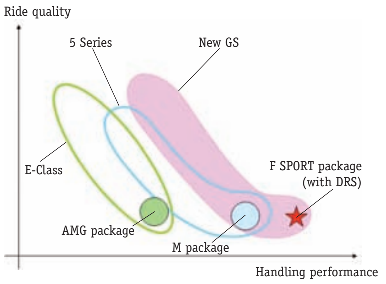
Vehicle occupants tend to feel discomfort when subjected to oscillations in the direction of roll, so the other key area for AVS development on the new GS focused on roll-oriented vehicle body control and advanced pitch control for a flat ride. By conducting linked control of all four wheels, it is possible to optimize lateral tilting (roll attitude) and fore-aft tilting (pitch attitude), as well as tilting solely in vertical direction as with the current model, helping to assure ride comfort.

Roll attitude control is conducted based on steering-angle sensor signals and lateral-acceleration signals from the yaw rate and linear *g* sensor. By controlling damping force when cornering to minimize the phase difference between roll angle and pitch angle, it is possible to maintain a vehicle attitude conducive to the comfort of the occupants, while helping to achieve handling that feels exceptional.

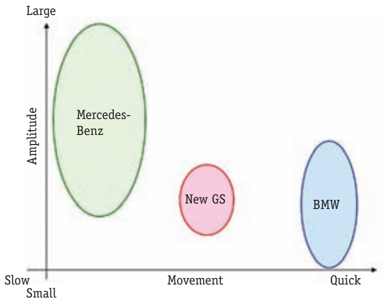
To realize comfortable handling performance, roll attitude control has been evolved with the focus on the system that senses vehicle conditions. By using not only the steering angle sensor, but also lateral acceleration signals from the yaw rate and linear *g* sensor, vehicle conditions when cornering can be detected with a greater degree of accuracy. Damping force switching is conducted optimally and smoothly, helping to achieve natural and smooth vehicle attitude changes when cornering.



FAR RIGHT: **UNDERFLOOR BRACE OPTIMIZATION**



RIGHT: **POSITIONING OF THE NEW GS F SPORT'S DRIVE CHARACTERISTICS: F SPORT PACKAGE WITH DRS MORE CLEARLY DEFINES THE NEW DRIVING EXPERIENCE**



BELOW RIGHT: **REALIZING VEHICLE BEHAVIOR THAT IS UNAFFECTED BY THE ROAD: COMPARISON OF VEHICLE MOVEMENTS IN RESPONSE TO INPUTS FROM THE ROAD SURFACE**

membrane (patent pending) makes a substantial contribution to shock reduction. An auxiliary fluid chamber in the bushing is made available by adding the rubber membrane and making a flow path. Fluid in the main fluid chamber pushes out the rubber membrane, causing fluid in the auxiliary fluid chamber to pass through an orifice to the main fluid chamber, thus keeping in check the pressure rise of the main fluid chamber.

Changing the bush characteristics has contributed to a 26% enhancement in handling stability, 30% better shock reduction, and a 33% enhancement in composure compared with the current model.

There is further innovation in the stabilizer bushes. To bring out the effect of the stabilizer bush more quickly from the stage of initial steering input, a new-construction stabilizer bush (also patent pending, *see p46*) has been used. It reduces the hysteresis width by 58% with respect to the current-model GS, helping to realize an integrated feel between steering operations and vehicle behavior, with a natural roll feeling.

A final important change at the front of the car is the increase in castor trail, which is designed to improve stability both in a straight line and when cornering.

That desire for better stability is also at the heart of the structure and geometry decisions incorporated into the new rear suspension, which simultaneously achieves high degrees of lateral force steer and steering rigidity.

By optimizing the arm layout, the toe curve is linearized and there is greater stability when external disturbances are encountered. The anti-lift/squat ratio has been increased, helping to enhance the vehicle's attitude under braking and acceleration, and vehicle attitude during cornering has been improved by optimizing the roll center to promote parallel roll.

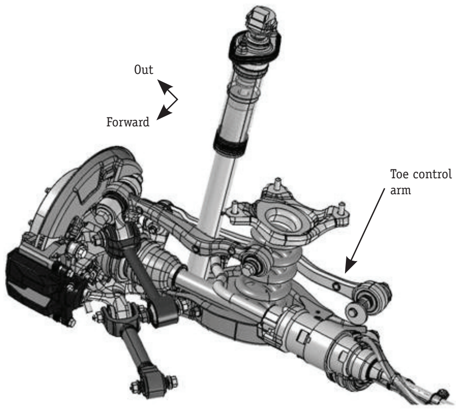
Increasing the compliance fore and aft of the axle, and promoting backward tilting of the suspension stroke locus, have helped to reduce harshness shocks. Further ride comfort benefits derive from the switch to aluminum construction for the upper No. 2 arm and toe control arm, both from reduced unsprung mass and higher rigidity. High-tensile steel sheet is adopted for the newly constructed, lighter upper No. 1 arm, lower No. 1 arm, and lower No. 2 arm. The lower No. 2 arm coil and damper are laid out separately for increased luggage space, the arm adopting a 'saucer structure' that bears the coil's lower end. A resin aerodynamic cover is attached to the arm, with good aerodynamics from the horizontal cover bottom.

The die-cast aluminum carrier has a spacer inserted in the ball joint fastener of each arm, helping to ensure high reliability, as does the slide pin inserted in the upper No. 2 bush fastener.

The new GS is available with both conventional passive dampers and adaptive variable suspension (AVS), which adjusts the damping force according to road surface conditions and driving style (*see sidebar, p44*).

Monotube-type dampers are adopted to help obtain stable damping force, with polyurethane bound stoppers to reduce shocks. Upgrading the oil, oil seal, and valve on the AVS-equipped car has contributed to smooth sliding and damping characteristics.

The GS represents something of a change in damping philosophy for a Lexus product to what might be termed a more European style. The car is relatively soft in bump, using all the wheel travel to absorb the input where required, with a rebound damping rate that has been substantially increased from the outgoing model. This enhances road surface tracking and the feeling of ride quality. Generating damping force from extremely low vehicle speed helps to realize linear vehicle response to steering inputs. The connection between damping force and responsiveness has been enhanced, helping to suppress unnecessary movements in the sprung mass.



TOE CONTROL ARM LAYOUT (PROTOTYPE). THE ARMS CONTRIBUTE TO NEW GS HAVING 15% MORE CORNERING GRIP THAN BEFORE

The final important piece of the GS's chassis jigsaw is the new steering system. The Lexus Dynamic Handling system (LDH) is a new system for Lexus that, by computing the optimum steering angles for all four wheels, achieves a high measure of vehicle responsiveness in line with what the driver expects, as well as constantly stable vehicle behavior.

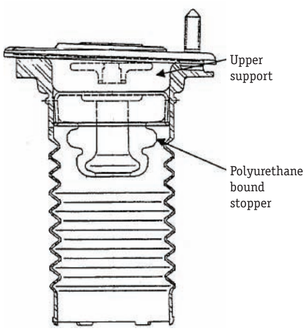
In the new GS line-up, LDH is available as part of the new, range-topping F Sport model, which has the highest level of dynamic performance.

LDH adds dynamic rear steering (DRS) for controlling the rear-wheel steering angle to the carry-over variable gear ratio steering (VGRS) system controlling the front-wheel steering angle. DRS has been developed from the rear-steer technology seen on the Toyota Aristo in the past. Unlike other manufacturers, Lexus uses the same supplier for both DRS and VGRS, and the same control system works the two together for the best possible integration between them.

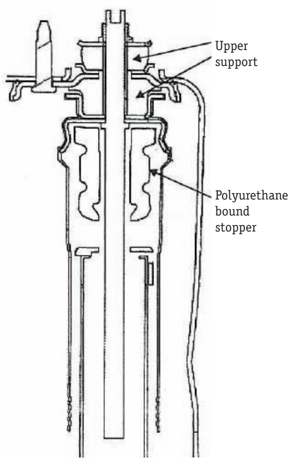
Combined with the EPS to control steering torque, LDH controls the steering output angles front and rear to provide vehicle responsiveness and stability in line with driver expectations, while helping to realize high agility. At the limit, active control of the steering angles is integrated with braking control, to help achieve the ultimate in kinematics.

The direction and magnitude of the VGRS and DRS output angles are computed from the objective vehicle characteristics set according to vehicle speed and a vehicle dynamics model.

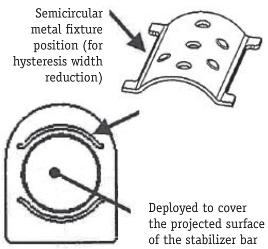
In the low-speed range, to impart the same kind of feel as the conventional 2WS car without the driver being aware of anything unusual, the amount of steering input necessary by the driver has been reduced by setting a high yaw response for the given driver steering angle. To reduce any unusual feeling due to the high yaw response and to shorten the turning radius, the vehicle orientation



FRONT UPPER SUPPORT AND BOUND STOPPER



REAR UPPER SUPPORT AND BOUND STOPPER



STABILIZER BUSH STRUCTURE

on cornering is set more toward the inner side of the turn than on the conventional 2WS model. The maximum amount of steering input necessary during stationary steering and when performing a U-turn has been reduced by 25%, and the vehicle's turning radius has decreased by a maximum of 20cm.

Realizing a high yaw response in the medium-speed range enables a comfortable vehicle response to the driver's intentions in driving situations where there are many corners, such as in urban areas and on winding roads.

To relieve anxiety during high-speed cornering, and simultaneously achieve substantial peace of mind and dynamic performance that demonstrates the vehicle response the driver expects, two key measures have been implemented.

In contrast to the conventional 2WS model, which tends to be oriented more toward the inner side of the turn as vehicle speed increases, the vehicle body slip angle is set near zero irrespective of vehicle speed. In addition, the responsiveness of the vehicle's lateral motion has been increased, and the time difference with the vehicle's yaw rate is set at approximately zero.

LDH comprises the VGRS actuator and controller as well as the DRS actuator and controller. The DRS actuator is a compact structure consisting of a brushless DC motor, reduction gear, and trapezoidal screw laid out coaxially, with the tie-rods joined to the rear suspension's toe control arms.

To steer the rear wheels, the motor torque goes through a speed reduction via the sun gear at the rotor end and planetary gear arrangement, and the rotation of the carrier is transferred to the trapezoidal screw. By the trapezoidal screw, the rotation is converted to a rod stroke, which steers the rear wheels up to a maximum of 2° in both directions.

Tuning notes

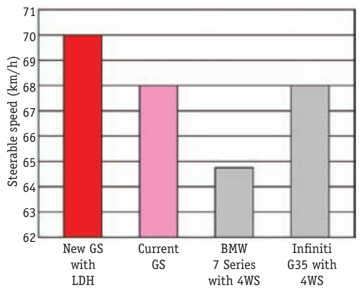
The importance attached to getting the GS and its N platform just right can be seen both in the one million development kilometers that the car racked up, split just about equally between mules and representative GS prototypes, and in the number of management ride-and-drives. For a typical new vehicle, the author would participate in about three such sessions; for the new GS, the figure was seven.

Handling was the focus for this car, because in the past it hadn't been at the level of some of the GS's main competitors. Initially, this led to the car handling superbly on a racetrack, to the detriment of on-road ride comfort. The issue was how to get the required body control and compliance into the car, but retain the roll control and handling response.

Even in early 2011, there were still issues in this regard with the AVS-damped versions of the GS. We wanted all derivatives to be as good as the 2.5-liter V6-engined, passively damped car, but we weren't satisfied that the ride comfort was at an acceptable level on the adaptive damper. So we went back to the damper manufacturer, which came up with some new valves that finally allowed the car to settle over small inputs. After that, we understood what we could do with the car and it wasn't so difficult then to do the final suspension tune, which is common to all markets.

Rear steer is fantastic at keeping a car stable in long, high-speed corners, but it can kill the agility on a country road by trying to make every corner a smooth one, which isn't representative. We did a lot of work to determine at what point the wheels help you, and at what point the wheels make the car move smoothly from side to side. Below 80km/h the rear wheels move in the opposite direction to the front ones; above that speed, they turn in the same direction.

We then tuned the steering feel to give the perception of what the car is doing. We dialed in a bit more build-up through the wheel and some feel of what the car was going to do. We wanted a little more feedback, a bit more kickback in the steering.

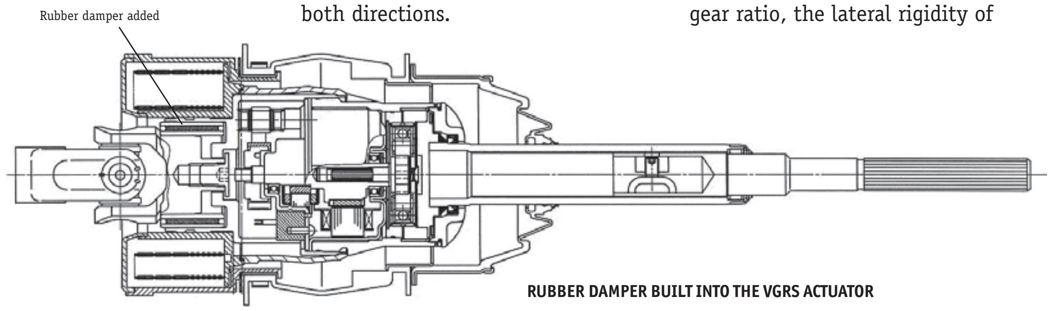


GERMAN ELK TEST ON THE TOYOKORO TEST COURSE

On the front axle, all GS models adopt a rack-assist EPS, realizing a more direct feel when Sport+ mode is selected. The gear ratio has been changed to 10.3:1 from 11.5:1 (without VGRS) and to 12:1 from 17.2 (with VGRS). In changing the gear ratio, the lateral rigidity of the gear mounting bush has been raised and internal gear friction has been reduced, as it has in the steering column's intermediate shaft. Together with the optimized EPS assist characteristics, these measures help to enhance vehicle dynamic performance and steering responsiveness.

Improvements have been made to the VGRS active steering system, too. The driving feel during lane-changing and driving on winding roads has been enhanced by correcting the vehicle's response lag to steering angular velocity. The actuator also has a new structure with a built-in rubber damper, located between the VGRS motor and reduction gear unit and steering wheel, for quieter operation.

The effectiveness of the steering response is heightened by the more rigid front suspension arms, bearing, and knuckle, and the increased spring rate in the steering gear support bushing and front lower bushes. This is symptomatic of how the new components right through the chassis work together to achieve a sense of unity between driver and car.



RUBBER DAMPER BUILT INTO THE VGRS ACTUATOR

Active for life?

ACOCAR IS TENNECO'S LOW-PRICED, HIGH-ISH BANDWIDTH ACTIVE SUSPENSION SYSTEM. **KEITH READ** PROVIDES THE BACKGROUND AND **JOHN MILES** TAKES AN ACTIVELY SUSPENDED FORD S-MAX FOR A SPIN

"CES's modular design enables us to serve all markets. But the focus of CES is off-road and commercial vehicles"
Koen Reybrouck, global ride control technology director, Tenneco

For decades, active suspension has been a holy grail for countless vehicle dynamics engineers around the world.

Now, after some false starts elsewhere, a team from Tenneco claims to have pioneered a viable active suspension, following many years of laboratory and development work to resolve the key issues. But despite the breakthrough, Tenneco says the world is not yet ready for active suspension and we must wait until 2014 or 2015 before seeing its system on production cars.

However, Tenneco clearly believes the world is ready to learn about its ACOCAR active suspension, even if production is a few years away. After a presentation at the 2010 Vehicle Dynamics Expo conference, the Illinois-headquartered designer and manufacturer of ride control products invited several European motoring writers to the MIRA proving ground in the UK in the summer of 2011 to learn about ACOCAR.

Journalists, including *VDI*'s John Miles (*see panel, below*) were allowed to experience its qualities when fitted to Audi and Ford demo cars, and to grill Tenneco's suspension team leaders on the design and development of their active system.

ACOCAR is a logical extension of suspensions developed by Tenneco over the past eight years, starting with the semi-active continuously controlled electronic suspension (CES) system launched in 2003. Subsequent developments include DRiV – digital ride control valve technology for B/C sector vehicles, offering low-cost fast-acting damping adjustments without a dedicated ECU – and dual-mode damper technology for small and mid-sized cars, where drivers select from two settings (comfort or sport) via a dashboard button.

"CES's modular design enables us to serve all markets," says Koen Reybrouck, Tenneco's global ride control technology director. "But the focus of CES is off-road and commercial vehicles."

The expectation is that by 2015, 30% of commercial vehicles will employ CES.

As R&D continued, CES was followed by the Kinetic H2/CES system, which integrated Tenneco's Kinetic H2 with CES technology by combining advanced mechanical and hydraulic systems with intelligent electronics. Advantages include improved performance with reduced power consumption, weight, space requirements, and cost, and it is this system that features on McLaren's MP4-12C. ➤

John Miles' verdict

Ever since Lotus's fully active suspension appeared back in 1983, a number of lower bandwidth body control systems have been introduced, all trying to productionize a little of what was achieved at Hethel.

Lotus Active was capable of controlling all body modes and hub motion up to 30Hz, but it needed oil pressure of 175 bar (2,500psi) and, at maximum workload, an awful lot of oil flow to do it. Plus it needed a fly-by-wire feedback loop from a tri-axial accelerometer pack, steering angle and rate measurement, vehicle speed, strain gauged suspension, and damper piston rods, as well as linear potentiometers on the dampers.

All control functions – body pitch, heave roll, roll stiffness distribution, ride heights, damping – were dictated by Moog valve-controlled actuators so powerful that the early versions had no coil-over units but depended entirely on the software control laws and hydraulic power to 'synthesize' springs. Constantly adjusted actuator positions compensated for changes in tire loads and wheel position. Roll inwards, pitch up under braking, variable roll stiffness distribution, and any other experimental modes were instantly available.

For research purposes it was a great system, but there was never a hope in hell of making a production version, if only for problems related to very high cost, power consumption, friction, weight, actuator mountings, awful system NVH, feedback stability, and failure mode safety – the very drawbacks that ACOCAR appears to eliminate without becoming just another low-bandwidth leveling system.

The beauty of ACOCAR is that it is a simple extension of Tenneco's well-proven (and effective) CES constantly variable damping technology. It uses the same solenoid controlled damping valves within struts, which now have fast-acting hydraulic leveling or wheel position-restoring capability, enabling anti-roll bars to be deleted. System pressure required is only 2 bar (yes, two!) with flow rates between 2 and 6 liters/min from a PAS oil pump. Existing CES system vertical body acceleration sensors and suspension displacement transducers, plus the normal CAN sensing for steering angle, rate, throttle, lateral acceleration, brake pressure, and vehicle speed are employed.

When system demand is low, such as when driving straight ahead on smooth roads, oil simply circulates through the suspension struts as in an open

ALBEIT UNSCIENTIFICALLY, THE IMAGES INDICATE THE FLAT BODY CONTROL THAT RESULTS FROM ACOCAR REPLACING CES ON AN OTHERWISE IDENTICAL FORD S-MAX

center power-steering valve, thus demanding very little power. Tenneco claims up to 15Hz response time for the solenoid valving and enough restoring force capability to enable 80% roll compensation (better than the ARBs it replaces), so there is nothing like the power of Lotus Active, but as we found out, plenty enough authority for a road car.

The clever bit is that piston rod force, therefore body angle restoring loads and damping, are partially generated by closing valves, rather than opening them (as in the Lotus case), thereby saving a great deal of power. ACOCAR doesn't do any real work (unless tuned to do so) in the straight ahead mode, when it simply becomes a CES damped system consuming very little power and generating little more than passive damper levels of friction as a result. To prevent forces going V squared on big rebound and compression inputs, the CES orifice-type poppet valves and the parallel passive valving feature spring-loaded blow-off valves.

After the initial MIRA ride and handling circuit launch of a barely tuned ACOCAR system, we were subsequently able to get a full morning's running on Norfolk's rough-surfaced lanes. The extremely flat body control in all modes was again confirmed, but also the excessively sharp metallic impact harshness on sharp edges or gulleys. Road surface noise remained a point worse than the comparator Ford S-MAX with CES.

The marvel of dialing-in ride changes with a laptop became apparent as we made six subtle changes in heave and pitch damping, as well as alterations to oil pump flow rate, all in about 90 minutes, managing to give the car a more relaxed, flowing gait, in contrast to its earlier, 'critically damped' feel, the downside being slight initial roll gain. Impact noise was now a little better too, yet primary body control remained spookily flat when thrashed.

ACOCAR seems to be making real progress, but I suggest that combining this much body control authority with the standard S-MAX's compliant feel over high-frequency inputs is the challenge (as ever), and Tenneco engineers agreed there is work to do on the standard-fitment strut top-mounts.

This is not just another roll/height leveling system, but perhaps the first ever cost-effective, high-ish bandwidth, true active suspension system, with little, if anything, of the power absorption, system noise, friction, failure mode, and cost issues that bedeviled engineers at Lotus. Also absent seem to be the peculiar losses in control feedback (basically lack of feel) that were experienced by Lotus and others trying to do the same job back in the 1980s and 1990s.

ACOCAR SHOCK ABSORBER

TENNECO'S SUSPENSION DEMONSTRATORS IN THE SLALOM CONES AT MIRA PROVING GROUND

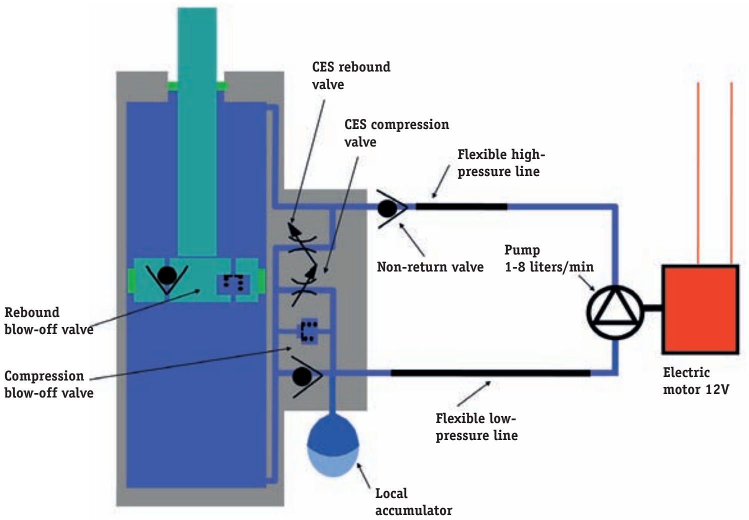


DIAGRAM SHOWS A SIMPLIFIED CROSS-SECTION OF AN ACOCAR DAMPER AND THE SYSTEM ARCHITECTURE

JUST AS IN THE H2/CES DAMPER SHOWN ABOVE, THE DAMPERS IN THE ACOCAR SYSTEM EACH HAVE TWO CONTINUOUSLY VARIABLE CES VALVES

For the Kinetic H2/CES system, front and rear anti-roll bars and shock absorbers are replaced with four double-acting hydraulic cylinders, two integrated CES damper valves, two roll accumulators, an automatic pressure maintenance arm, a comfort valve with integrated comfort accumulators, and interconnected hydraulic lines. The CES damper valves at each corner restrict the flow between cylinders and accumulators to electronically control roll, bounce, and pitch modes, allowing decoupling of transient ride and handling performance.

This interconnected passive-reactive system provides continuously controlled damping and high roll stiffness with reduced warp and articulation stiffness. Vertical tire loads are more equalized, resulting in significantly improved traction. The continuously controlled damping works with the skyhook principle for body control, with added algorithms for wheel hop control, steering, braking, and acceleration. Use of the electronically controlled CES damper valves, in combination with intelligent control algorithms, allows independent control of body and wheel motions.

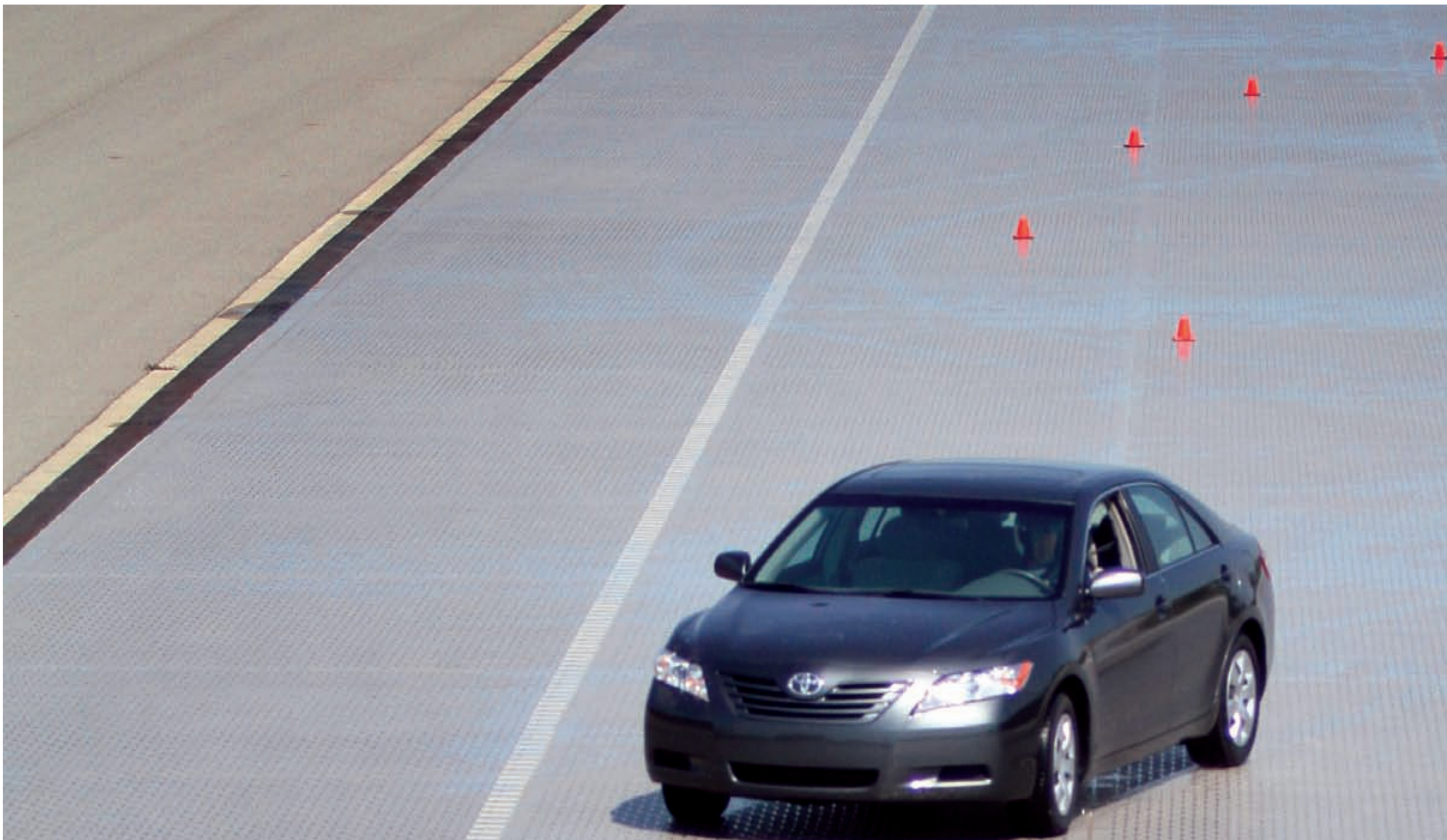
Enter ACOCAR, Tenneco's fully active system, whose design is now deemed sufficiently mature to place in the public domain.

Just as in the Kinetic H2/CES system, ACOCAR includes shock absorbers with two continuously variable CES valves each. But it also features the addition of hydraulic pumps to bring energy to the suspension, resulting in even more control on effective damping and spring forces.

Oil is constantly circulated, via the pumps, through the shock absorbers, whose damping valves can each be closed independently to make the car body move up when it would otherwise be moving down, and vice versa. The system works to keep the car body flat at all times while controlling wheel movements to improve tire-to-road contact. The addition of a pump at each corner means the system does not depend on the movement of the wheels alone to generate damping force. Meanwhile, the pump flows are continuously adapted to the vehicle needs to reduce power consumption to levels that are lower, claims Tenneco, than the use of headlights.

Reybrouck believes the ACOCAR system controls roll, pitch, and heave better than any other suspension system on the market, resulting in superior benefits in terms of handling, safety, and comfort.

It's very much what you would expect him to say. But is he right? We'll know the true verdict in due course; in the meantime, refer to the previous page to see what John Miles thought!



Little marvel

FOWLERVILLE PROVING GROUND IS A SMALL FACILITY WITH BIG AMBITIONS AND SOME UNIQUE FEATURES. **ADAM GAVINE** WENT TO MICHIGAN TO PAY IT A VISIT

FOWLERVILLE BOASTS BASALT AND CERAMIC PAVEMENT TO SIMULATE SNOW AND ICE SURFACES

Michigan has no shortage of proving grounds, so while the giants such as Ford, GM and Chrysler offer all-encompassing facilities, the smaller players need an angle. Thus, while Fowlerville Proving Ground may span a relatively modest 870 acres (3.5km^2), some notable features are attracting major OEMs and suppliers.

Built in 2005 by parent company Aisin as an independent subsidiary (officially named FT Techno of America) and as a test ground for its own technologies, the facility has benefited from new features year on year. The initial benefit that strikes you is its seclusion. Located near the town of Howell, about 50 miles from Detroit, once off the freeway you drive down secluded roads lined by cornfields and ultimately a rough track, with the proving ground at a dead end. Perimeter fencing means you can barely tell the facility is there, let alone spot prototypes.

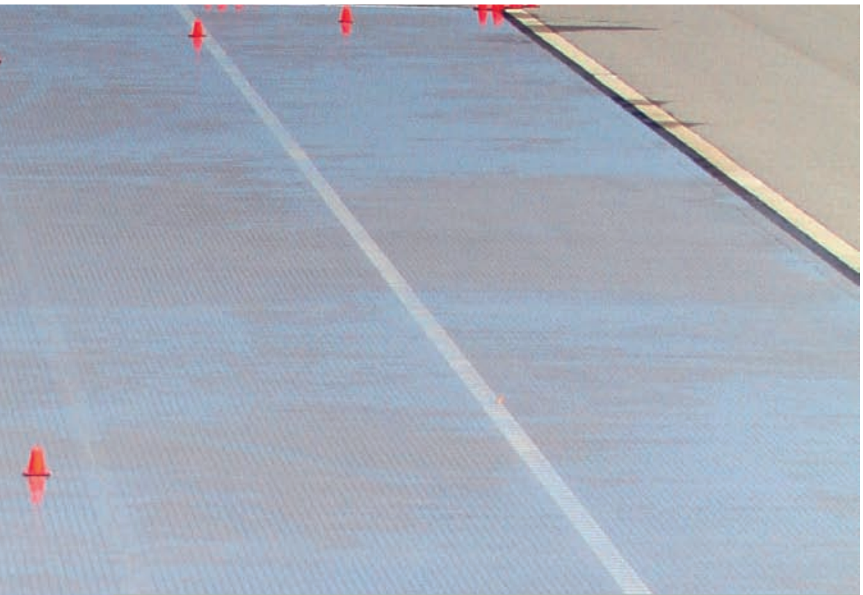
Enter the facility and you find that within the fenced boundary are tall berms, topped by trees for extra security from prying lenses, and further berms and trees between test areas, so clients can have privacy from one another. The berms also reduce noise, although there are few neighbors to trouble.

The facility is dominated by its three-mile oval comprising two 12ft-wide asphalt lanes with a friction coefficient of 0.95 ±0.05, which the company admits is not the biggest oval on offer in the area, but then performance testing is not its focus.

As Terry Takano, vice president of FT Techno, explains, "Our track is closer to the real-life road situations. Most OEMs have a huge oval track of 10 miles (16km), but if you want to replicate real-world roads, city streets and freeways, we can do that here. We do not need a huge oval."

This real-world focus is reflected in the 100mph (160km/h) speed limit on the oval, although it can be raised on request, following risk assessment and implementation of "countermeasures". The speed limit is also largely dictated by the 4,500ft (1,371m) straightaways and that the ends have a mere 7° banking ("There are no banks in the real world," says Takano).

One of the straightaways adjoins Road A, the first feature to be opened at the facility, which is identical to the oval's straights, being the same length and coefficient of asphalt, but



Scooby Doo, where are you?

The Fowlerville Proving Ground is built on land that originally comprised six different farms, a fact that you cannot escape on the site, as various barns and farmhouses have been kept. The road on which the site stands is Smith Road, named after a former landowner, and a decommissioned stretch still runs through the facility, complete with roadsigns. As a further nod to Smith heritage, the 130-year-old family home has been fully renovated with new hardwood floors and filled with antique furniture, and it can be hired for meetings, events, or just as a nice base for executives. Operations manager Mike Benjamin insists the house is haunted, but don't let that put you off (he has admitted to being a Scooby Doo fan).

Drive down the Mack Road, a rather more recent road name in honor of the first president of FT Techno, Masanori 'Mack' Yuasa, and a further, more modest, farmhouse has also been restored, which can be used for meetings and barbecues.

with four lanes and a turnaround at each end.

The proximity of that straight to the oval – at one point they are separated by nothing more than two yellow lines – reminds one of the importance of safety. There has never been an accident at Fowlerville, and they are doing everything they can to prevent one happening. Hence every vehicle that enters the tracks must be fitted with a GPS device, a datalogger and a radio antenna, which communicate position and speed in real time to the admin building, where FT Techno staff use special software to monitor an aerial view of location and speed.

The software is remarkable in that it reduces a complex task to a one-person job, also aided by a series of cameras located all around the site. Various limits can be set, such as speed or lateral *g*, and if they are exceeded, track control is alerted and can radio the offending driver. In addition, a geofencing setup can automatically monitor a vehicle's time or distance on a track for billing purposes. If an accident does happen, a licensed first responder is on staff, and an EMS vehicle with emergency medical and extraction equipment is on site.

Within the oval lies a 1,000ft diameter, 20-acre dynamic pad, which can be accessed from three 1,350ft approach/departure lanes. The asphalt pad, being only four years old, is in great condition, with a friction coefficient of 0.95 ±0.05.

There are markings for 30, 60 and 100m constant radius tests, as well as for single and double lane

CLOCKWISE FROM BELOW: **THE BRAND NEW RIDE ROAD AT FOWLERVILLE HAS A SURFACE THAT REPLICATES THE PUNISHING FREEWAYS OF LOS ANGELES; LOW-μ AREAS CAN BE FLOODED FOR WET-WEATHER OR ICE WORK; RANGE OF TEST EQUIPMENT AVAILABLE TO CLIENTS INCLUDES AN ABD SR60 STEERING ROBOT**

changes, with solid white, dashed yellow, and Botts' dots. Made using reflective asphalt marking tape, the lane markings are in place from a previous government test program, as the National Highway Traffic Safety Administration (NHTSA) has been carrying out lane departure prevention system tests so it can set OEM specifications. As with the coast-down testing on the oval, OEMs can use this pad to develop such systems using the same facilities as the official body. Further marks can be added at customer request.

While there is enough room on the pad that test drivers should not find themselves exiting it unexpectedly, if they do, there is some grassy run-off, which, while not especially smooth, is fairly unimpeding.

Driving away from the oval area, via some disused public roads the site now sits on – complete with roadsigns – you arrive at the 48,000ft^2 friction surfaces. There are two 700ft-long lanes, one a 30ft-wide low-μ ceramic surface for simulating ice, with a friction coefficient of 0.09-0.12 when wetted by the underground sprinkler system. The other is a 51ft-wide basalt lane for simulating snow, with a friction coefficient of 0.25-0.35 when wet.

The lanes are accessed by a 1,350ft-long straight, level, asphalt road with a dry coefficient of 0.95 ±0.05, and the asphalt continues between and to either side of the friction surfaces so multiple μ configurations can be tested in either direction. The test driver is given a remote control for the sprinkler system, and for safety reasons, only one vehicle can test in this area at a time.

Of course, given the notoriously cold Michigan winters, ice and snow are not rare. To ensure the surfaces, even the slippery ones, are kept in a quantified and repeatable condition, during snow season, all surfaces except the tiled surface are plowed every day for year-round operation.

"I don't think many Michigan proving grounds operate their dynamics pads in the winter. Ours is the perfect size – it's big enough at 20 acres to be useful, but if it was bigger it would be impossible to get the snow off every day," says operations manager Mike Benjamin.

Should a customer need real ice in the winter, the asphalt areas can be flooded on request, and snow can be piled up for automotive snowplow tests on transmissions, etc.

Back at the main building, there is a large garage split into two 6,000ft^2 units, each accessed via access card security, and fully stocked with hand and power tools, four vehicle lifts with an exhaust system, an alignment rack, scales, a machine shop, secure parking, and office space with kitchens and wireless internet. Should a customer need any additional tools or equipment, Fowlerville staff will endeavor to source it the same day as part of the service, and will simply add it to the inventory. In addition, a gasoline and diesel fueling station is on site, with fuel sold at cost, and there is also an automatic car wash.

Further buildings include a brand-new garage building where FT Techno can do turnkey testing work for customers, although depending on availability this could be used as a further client garage. Again, this building can be split into two areas with mirror features. There is also a small garage building right on the edge of the oval, which can be used for quick tire changes, etc, with an adjoining cold soak trailer.

VDI SAYS

Fowlerville does not offer the 'one-stop shop' that some of the giant facilities nearby can. However, its size can also be its advantage, offering a personal level of service to customers and some flexibility in its operations. As is typical of Michigan, the site is very flat, and those looking for gradients or off-road areas will have to look elsewhere, unless such features fit into the facility's future plans. Those looking to test exotic machinery may also find the site a little limiting due to its low speed limit and small oval. However, as active safety gains importance, the facility – originally designed with such work in mind – is now really paying off.

Innovative simulator

ABOVE: **THE SIMULATOR'S HIGHLY IMMERSIVE VISUAL EXPERIENCE.** BELOW RIGHT: **CORRELATION BETWEEN THE P-CAR (BLUE) AND THE SIMULATION (RED). THE PLOTS SHOW SPEED (TOP), STEERING ANGLE (MIDDLE), AND LATERAL ACCELERATION (BOTTOM)**

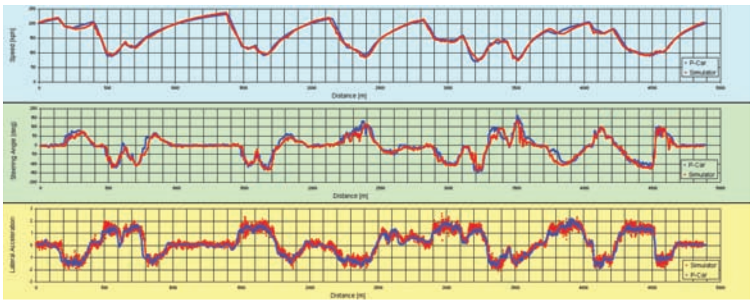
VI-DriveSim Dynamic is the first affordable, high-fidelity, 'hardware and driver-in-the-loop', full-motion vehicle simulator available to the general automotive industry. The simulator is the result of a collaborative effort between Multimatic, VI-grade, Concurrent, SimCoVR, and Ansible Motion, and was publicly unveiled in May 2011 at Vehicle Dynamics Expo.

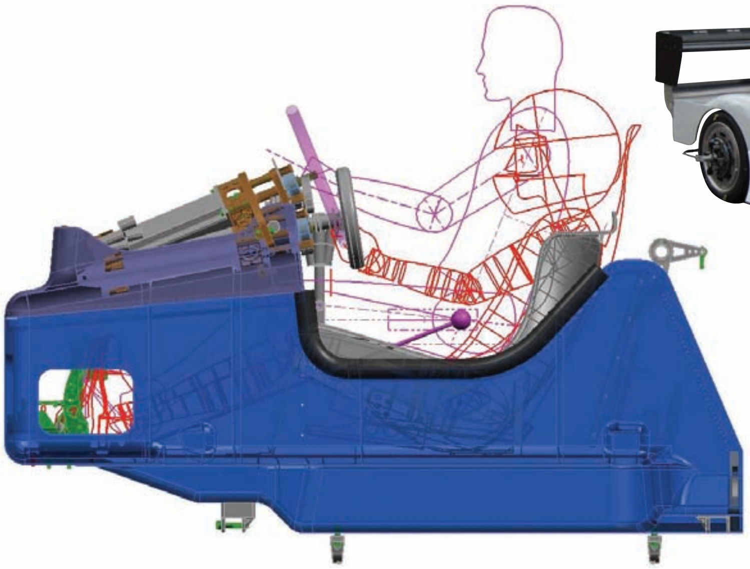
The use of driving simulators in the motorsport and road car industries is well documented and their value to development and tuning engineering is widely accepted. All the front-running Formula 1 teams rely heavily on their driver-in-the-loop (DIL) simulators to make strategic decisions on new hardware development, as well as race weekend setups.

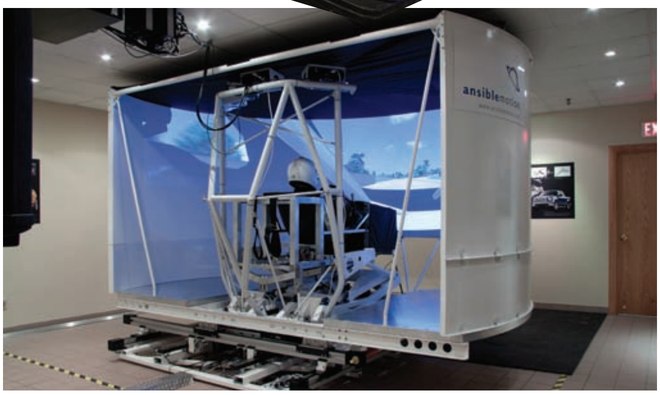
Mercedes-Benz utilizes a highly sophisticated DIL simulator as the primary tool in the development of its vehicle stability control. There are aspects of its driver aid systems, such as Pre-Safe braking, that could not be safely tested in any other way.

However, the simulators utilized by OEMs and the highest-level motorsport organizations are purpose-built, large-scale installations that in many cases have taken several years to develop at costs well in excess of US$20 million. VI-DriveSim Dynamic has been developed to offer the same capabilities in a turnkey, fully integrated, and affordable package.

VI-DriveSim Dynamic is an integration of the world's leading







real-time vehicle dynamics simulation software, a proprietary six-degree-of-freedom (6DOF) motion platform, high-definition graphics, state-of-the-art motion cueing and a highly configurable driver interface. This complete turnkey, office environment vehicle simulator solution was the vision of VI-grade's technical director, Diego Minen.

At the heart of VI-DriveSim is VI-CarRealTime, a multibody analysis engine that provides real-time, high-fidelity, fully dynamic vehicle models. VI-DriveSim is used to integrate the analysis engine with an immersive graphics and high-resolution visualization program developed by SimCoVR. VI-DriveSim enables a seamless combination of any source of real-time signals and instantaneous two-way synchronization with Adams/Car, the de facto worldwide standard solution for automotive engineering.

Ansible Motion has developed a proprietary 6DOF motion platform for VI-DriveSim Dynamic. This unique design departs from the industry-standard Stewart platform (hexapod) to better serve the needs of vehicle simulation.

Whereas a hexapod was originally conceived for use as a flight simulator, the Ansible Motion platform provides decoupled lateral, longitudinal, and yaw motion with large displacement capacity and full-range authority. This is in direct contrast to a Stewart platform, which loses authority as it moves away from its center position and is more capable in pitch, roll, and heave (important in aircraft simulation) than in lateral, longitudinal, and yaw (important in ground vehicle dynamics).

The Ansible Motion platform utilizes an innovative compact mechanism to provide coupled motion of the less important pitch, roll, and heave. The resultant 'clean' lateral, longitudinal, and yaw motions are important for providing the driver's vestibular system with appropriate onset 'cues', and as a result are far superior to what can be generated with a hexapod.

The visual cues are projected onto a 160°, 1.5m high, 4m diameter cylindrical screen, which moves in X-Y, while the projectors move in X-Y and yaw, allowing for a large field of vision and a highly immersive viewing experience. The total package is designed to fit within a standard office environment. Weighing only 1,000kg, the platform requires no floor reinforcement and therefore can be located within easy access of an entire vehicle development team.

To achieve the most realistic simulation, Multimatic has developed a highly configurable driver interface that consists of world-class steering feedback, flexible seating with high-frequency excitation, active pedals, and a range of force cues (belt tensioning, helmet loading, and so on) that aid in convincing a driver's vestibular system that they are on a real track or road. The cockpit environment also showcases Multimatic's expertise in lightweight carbon-fiber structures.

In addition to the development of the cockpit, Multimatic has undertaken extensive quality assurance of VI-DriveSim Dynamic using direct comparison of the DIL simulator with the company's fully characterized parameter or P-Car. Multimatic development driver, Scott Maxwell, has run hundreds of real and virtual laps of the company's lidar scanned and meshed test track, Calabogie Motorsports Park, in Ontario, to refine every aspect of VI-DriveSim Dynamic.

The traces in the plot (*opposite page*) show excellent correlation, but more importantly, Maxwell has repeatedly been able to demonstrate that even minor mechanical and aerodynamic changes made on the P-Car can be discerned on the simulator, and vice versa.

In summary, the combination of VI-grade's vehicle dynamics software, Ansible Motion's innovative 6DOF motion platform, and Multimatic's development of cockpit force cueing and rigorous quality assurance program, has resulted in a world-class, affordable, plug-and-play vehicle dynamics simulator.

TOP LEFT: **HIGHLY CONFIGURABLE LIGHTWEIGHT MULTIMATIC CARBON COCKPIT SHOWING RACE AND ROAD CAR ARRANGEMENTS**

TOP RIGHT: **THE PARAMETER CAR (P-CAR) USED TO VALIDATE THEORETICAL VEHICLE DYNAMICS AND TRACK MODELS IS EQUIPPED WITH WHEEL FORCE TRANSDUCERS AND MORE THAN 300 CHANNELS OF DATA ACQUISITION**

ABOVE: **THE SIMULATOR INSTALLED AT MULTIMATIC'S TECHNICAL CENTER, TORONTO, CANADA. IDENTICAL SYSTEMS ARE LOCATED AT THE VI-SIMCENTER IN UDINE, ITALY, AND AT ANSIBLE MOTION, HETHEL, UK**

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Automotive test systems

MAIN IMAGE: **A FOUR-WHEEL-STATION SPMM 4000HS WITH ABD DYNAMIC ARM WHEEL POSITION MEASUREMENT SYSTEM**

Anthony Best Dynamics Ltd (ABD) designs and manufactures test equipment for automotive development applications. ABD was founded in 1982 and initially provided automotive suspension design consultancy. More recently the focus of ABD's business has been the production of Kinematics and Compliance test machines and Driving Robots.

ABD's kinematics and compliance measurement machines are used by many vehicle and tire manufacturers to measure the suspension characteristics that are essential to understanding vehicle ride and handling. The Suspension Parameter Measurement Machine (SPMM) subjects a vehicle to a variety of forces and displacements and measures the kinematic characteristics due to the suspension and steering system geometries, and the compliances due to the suspension springs, anti-roll bars, elastomeric bushes, and component deformations.

A wide range of parameters are evaluated, including suspension stiffness and hysteresis, bump steer, roll steer, roll stiffness distribution, longitudinal and lateral compliance, steering system characteristics, etc.

Knowledge of these parameter values and characteristics is essential for a thorough understanding of a vehicle's performance in terms of ride, impact isolation, steering, and handling. The SPMM 4000 applies forces slowly, so as not to excite any dynamic forces emanating from inertias, dampers or elastomers. The SPMM 4000HS also has the capability to perform some tests at higher frequencies.

The SPMM accurately simulates the motions of the vehicle body upon the road because of its fixed ground plane design, which has several benefits. For example the diagram opposite shows how the SPMM can faithfully simulate the vehicle body roll motion that occurs during cornering by maintaining a fixed horizontal wheel plane and rolling the vehicle body using the SPMM's moving center table.

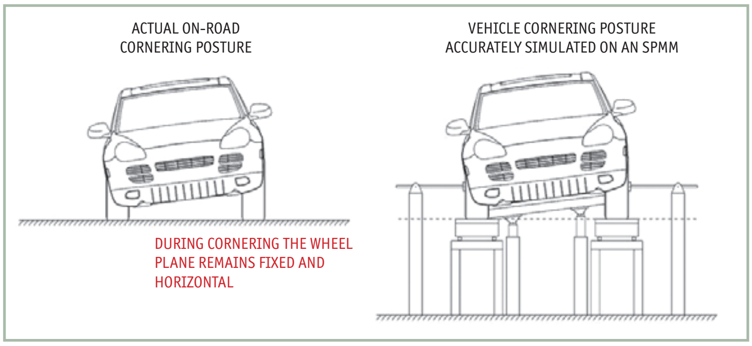
The SPMM uses Kistler multicomponent piezoelectric transducers to measure wheel forces. Kistler Piezoelectric load transducers are ideal for this application as they have high stiffness, low cross-talk, and higher sensitivity than the equivalent strain gauge devices and the short duration of K&C tests means the amount of force measurement drift that occurs is negligible.

The SPMM is supplied with either the draw wire encoder wheel position measurement system (WPMS) or the ABD Dynamic Arm WPMS. The draw wire system is a simple and highly effective solution that provides absolute wheel position measurements with very low cross-talk. The ABD Dynamic Arm option is recommended if higher frequency testing will be undertaken or higher measurement accuracy is required.

The SPMM is controlled with software running on a Windows PC using familiar conventions, which makes it easy to use. Tests are defined in tables that are easy to configure, meaning there is no need to learn a scripting language. The SPMM software is designed so that a single operator can safely load vehicles onto the SPMM and run tests.

After testing, ABD's MATLAB-based post-processing software compiles test reports containing plots of all commonly required parameters, including roll center, anti lift and dive coefficients, virtual swing arm lengths, steering ratio, Ackermann curves, scrub radius, mechanical trail, castor angle, and kingpin inclination.

The SPMM can be supplied as a four-wheel-station machine, which enables a full vehicle to be tested, or as a two-wheel-station variant that enables one axle to be tested at a time. The optional MIMS upgrade adds the capability to quickly and accurately measure the moments of inertia and center-of-gravity height of a vehicle.



LEFT: **SPMM SIMULATION OF VEHICLE BODY ROLL MOTION** BELOW LEFT: **SR60 TORUS STEERING ROBOT INSTALLED IN A VEHICLE**

ABD's Driving Robots are used for repeatable and objective testing of vehicle behavior on the track. Typical applications include the testing of vehicle steering and brake systems, as well as vehicle dynamics, durability and ADAS testing. The first steering robot system, supplied in 1997, is still in regular use.

The robots enable on-track testing to be performed quickly and accurately, meaning that high-quality objective data can be obtained without the need for highly skilled drivers.

A range of products has been designed for different applications. For example, steering robots are available with torque capacities ranging between 15Nm and 150Nm.

The robots are installed with little or no modification to the vehicle, and enable the driver to be seated in the vehicle as normal. All the robots are electrically powered and fitted with Class 3 electrical safety systems that ensure manual control of the vehicle can be regained by the driver.

All robots are easily programmed using a single Windows-based software interface, which is typically installed on an in-vehicle laptop or tablet PC. Real-time control of the robots is undertaken by a powerful real-time multi-axis servo controller that is linked to the PC via USB.

A choice of control electronics is available depending upon the robotic hardware being used. The controllers have the option to provide data capture and can also output data in real time for capture by external systems.

In a conventional Steering Robot test, the angular input that the robot will apply to the steering column is pre-programmed and the response of the vehicle is measured. ABD has developed a Path Following upgrade for the Steering Robot that instead enables the user to program a path over ground for the vehicle to follow. The vehicle position is measured using a GPS-corrected inertial navigation system. The robot uses a real-time feedback control algorithm to determine the steering inputs necessary to make the vehicle follow this path with high accuracy. Path-Following maneuvers can be performed that take the vehicle to the limit of adhesion offered by the tires.

By combining the path-following technology with the Brake and Accelerator robots, it is possible to perform tests without a driver in the vehicle. ABD has supplied several Driverless Test Systems for test applications where the risk of injury to the driver is high, or where the testing condition is arduous for the driver.

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HIL for driver training

RIGHT: **SIMULATOR INTERIOR**
BOTTOM: **GEOSPECIFIC DATABASE ILLUSTRATION**

The Minnesota Valley Transit Authority (MVTA) recently commissioned Realtime Technologies Inc (RTI) to design and develop a simulator system for its innovative bus-only shoulder operation program. Bus-only shoulders enable a bus to bypass congestion during morning and afternoon rush hours.

Although the use of the shoulder as a busway offers a number of advantages, it also imposes additional stress on the driver. The narrow shoulder leaves the driver a smaller margin of error. Operating with this smaller error margin is difficult during heavy traffic and poor weather conditions, during which the bus driver can choose to not use the shoulder, which increases travel time.

Given these challenges, the MVTA has partnered with the University of Minnesota Intelligent Vehicles Lab to develop a driver assist system (DAS) for these buses. The system provides two primary capabilities: lane-keeping information via differential GPS, and collision warnings via three multi-plane lidar scanners mounted on the bus to provide both side and front collision warnings.

The DAS provides alerts and warnings via a multimodal human-machine interface: graphically through a heads-up display (HUD); haptically through a torque-actuated steering wheel giving the steering wheel a restorative torque in the event of lane drift; and tactically through a seat equipped with actuators that vibrate on the side of the seat corresponding to the side of the bus that is departing the lane.

RTI developed a specialized bus simulator to support this project. The simulator combines hardware in the loop (HIL) and human in the loop (HITL) concepts to integrate hardware, software and operator elements into an effective simulated training experience.

The simulator itself consists of a driver cab appointed with the same equipment as the actual vehicle, a 200° field-of-view front-projected visual system, a 3DOF under-seat motion base, torque feedback steering, and a 35-mile geospecific database of bus routes used by the MVTA (with correlated data to allow for GPS coordinate tracking and generation of autonomous traffic). The simulator integrated the real DAS system as a HIL device.

RACING SIMULATION

Team O'Neil Rally School and the US Army Corps of Engineers have partnered with Realtime Technologies Inc (RTI) to provide a simulator to support the Army's Synthetic Automotive Virtual Environments (SAVE) project (*pictured above*). The SAVE project is designed to perform research in high-speed, loose-surface vehicles, tires, human dynamics – and to apply understanding to dynamic stability control systems, autonomous systems, tire-deformable road design, and ultimately to driver skills training.

Traditionally, organizations such as Team O'Neil and the US Army have offered driver training for both commercial and military applications. While effective, the cost, resources and properties required to support the training have proven impractical. A simulator, operable 24/7, can provide a significant increase in practice opportunities involving maneuverability in rough road situations.

RTI integrated an existing vehicle cab, pedal set, and motion base with RTI's SimForce steering system. The resulting simulator hardware includes a lightweight hardware base (114kg/250lb), a 120° field-of-view LCD visual system, and a 3DOF motion base.

RTI customized its SimCreator software to accommodate the hardware, generate realistic scenarios, and report simulation results. For this project, RTI's software supports four different vehicle models: HMMWV (Hummer), MRAP (mine-resistant vehicle), passenger vehicle with ABS, and passenger vehicle without ABS. Scenarios developed with the software include accident avoidance, rollover recovery, and soft shoulder recovery. Depending on the vehicle selected and the scenario defined, the software customizes the simulation experience to closely match real course conditions.

As participants interact with the scenarios in the simulator, RTI's software monitors multiple metrics including eye tracking, brake and steering reaction, accelerator use, and vehicle speed. These metrics are compared with those of professional course drivers to provide quantitative support for participant improvement in the simulated experience.

Team O'Neil founder Tim O'Neil believes that, "One of the biggest advantages of simulated drivers training is the non-subjective way a computer can provide feedback. Human driving instructors are not as consistent and take a significant amount of time and effort to develop. With simulated training we can put people in scenarios that we could never safely generate in a live environment. In that way simulated training is better than live training. But when you couple simulation with live training, it improves the experience and outcome overall."

From a training perspective, the simulator allows operators to train in optimal and sub-optimal conditions prior to on-road DAS training. It can also introduce on-demand scenarios to maximize training effectiveness and driver preparation for real-world DAS usage and eventual shoulder driving.

Geospecificity in the simulator is achieved through the creation of virtual worlds based on roadway data collected by mapping vehicles, then managed and manipulated by Realtime Technologies software applications.

During the simulation the autonomous vehicle positions are provided from the simulator to the DAS system and simulated in the real DAS peripherals. The DAS software draws the HUD and this correlates with the out-the-window view drawn by the simulator. The DAS software also draws the heads-down vehicle information displays. Torque is played back on the steering wheel based on DAS warning commands that are sent back from the DAS system to the simulator. The DAS system controls the haptic seat as required.

The perspective a driver brings is generally different to that of the developer, and the insights the end user provides typically produce a better system. In this case, driver experience with the system during the initial training period on the simulator resulted in a staged approach to lane departure alerts that was not initially included as part of the DAS design. The staged warning was easy to implement, and in hindsight, offers improved driver acceptance when compared with simultaneous warnings. Honest driver feedback, possible through use of the simulator training scenarios, resulted in a system that better meets the needs of the driver.

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Touring car dynamics

POLESTAR RACING WAS A FRONT-RUNNER IN THE 2011 STCC

Polestar Racing is a Swedish motorsport team, affiliated with the Volvo Car Corporation, currently competing in the Scandinavian Touring Car Championship (STCC) and World Touring Car Championship (WTCC).

Polestar has a stellar record, winning the Swedish Touring Car Championship team championship in 2009 and 2010 and coming second in its successor, the Scandinavian Touring Car Championship, in 2011. To succeed in this highly competitive environment, Polestar engineers spend months over the winter off-season struggling to squeeze a few extra tenths of a second per lap out of their cars.

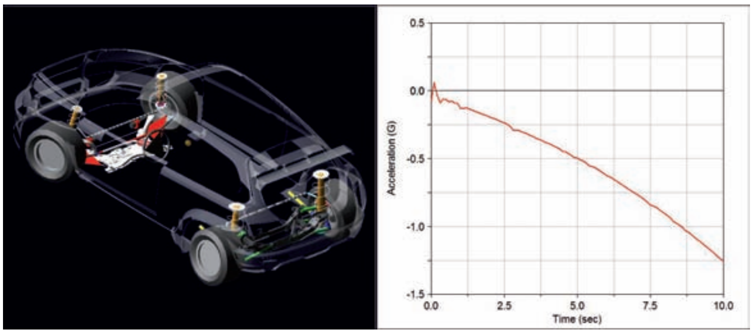
"We have many different ideas to improve race performance," says Per Blomberg, manager, chassis development at Polestar Racing. "But we can only spend four or five days every six weeks at the test track in southern Spain. We have a very intense schedule and the number of vehicle configurations that we are able to test is strictly limited."

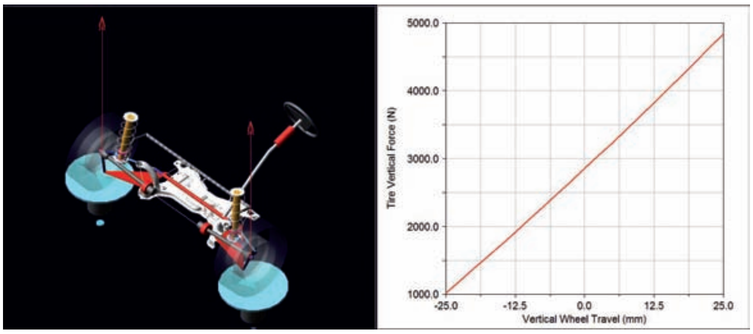
The team performs around 3,000km of track testing each winter with the new car, compared with the 150km or so that each driver covers in the course of a normal race weekend.

In the past, Polestar used hand calculations and spreadsheets to perform some very rough estimates of vehicle performance to attempt to select the best designs for testing.

"These tools provide some value in sharing knowledge, but contribute little towards predicting the performance of a prospective design," Blomberg says. "We have long used simulation at the component level to, for example, evaluate stress and deformation in suspension components, but we were not aware of the possibility of predicting the performance of the complete vehicle until the MSC representative introduced us to Adams/Car."

MSC Adams/Car is designed to enable engineering teams to quickly build and test functional virtual prototypes of complete vehicles and vehicle subsystems. Engineers create a model of the vehicle in Adams/Car to match a configuration that they are interested in evaluating. Working in the Adams/Car environment, engineering teams can exercise their designs under road conditions, performing the same tests they normally run in a test lab or on a test track, but in a fraction of the time.





LEFT: **EXAMPLES OF HOW ADAMS/CAR WAS USED FOR VEHICLE DYNAMICS SIMULATION FOR THE POLESTAR STCC VOLVO C30 RACER**

One of the main design parameters that Polestar engineers evaluate with Adams/Car is the location of the pickup points in the suspension – the points where the suspension link arms attach to the chassis. The front end of Polestar's current vehicle has a MacPherson strut with a damper that attaches to the body under the hood and a lower link arm that attaches to the hub. The rear end uses a multilink suspension. Other parameters that are evaluated during simulation include spring thickness, anti-roll bar thickness, camber angles, tire properties and weight distribution in the vehicle.

Adams/Car simulates the vehicle traveling through the turn. The driver enters the turn at the outer edge of the track, steers into the corner to the inside edge of the track at the center of the turn, then exits the turn at the outside of the track. The margin, the distance between the vehicle and the outer edge of the turn, is one of the most critical outputs of the simulation because the existence of margin indicates that the driver can increase the speed of the vehicle through the turn. Polestar engineers often run the simulation several times at different speeds in order to find the speed where the margin is zero. This is the maximum speed that the vehicle configuration under consideration can be driven through the corner.

The simulation also provides detailed information on the behavior of every aspect of the car that is included in the model. This information is often used by engineers to understand the reasons why one design performed better than another.

It is important to note that simulation provides much more diagnostic information than can be obtained from physical testing, which is limited by the relatively small number of sensors that can be positioned on the vehicle.

"The correlation between Adams/Car simulation and physical testing is very good," Blomberg says. "When we compare simulated to measured roll angle or lateral or longitudinal acceleration the results match up to the second or third decimal place. Our biggest challenge in making further improvements in simulation accuracy is getting accurate material information from the tire manufacturers.

"Adams/Car helps us decide which ideas we should go to the test track with and which ones we should forget about," he continues. "Before we used Adams/Car we found that only 40-50% of what we tried at the test track turned out to be effective. Since we began using Adams/Car, 80-90% of the ideas that we try on the track succeed. By enabling us to try out our ideas on the computer first, we can evaluate many more ideas than in the past and spend our scarce time at the track just on ideas that we are nearly certain will work."

As an example, the Swedish Touring Car Championship changed tire suppliers a few years ago. All the teams scrambled to better understand the behavior of the new tires. Polestar used Adams/Car to explore the effect of variables that influence the behavior of the tire on the full vehicle performance. Polestar discovered that vehicle performance was optimized at two very different combinations of tire pressure and camber. Both of these combinations were equally fast, but there were major differences in the way the vehicle handled, particularly in the degree of oversteer and understeer. They used this knowledge to select one set of conditions or the other depending on which type of behavior was best suited for a particular track.

Blomberg concludes that Polestar's experience with and intensive use of Adams/Car provides a significant competitive advantage and has played a significant role in the team's success.

"To win a race, you must understand the car," he says. "Adams/Car supports our success by enabling us to simulate the car for every vehicle configuration and track condition we can imagine."

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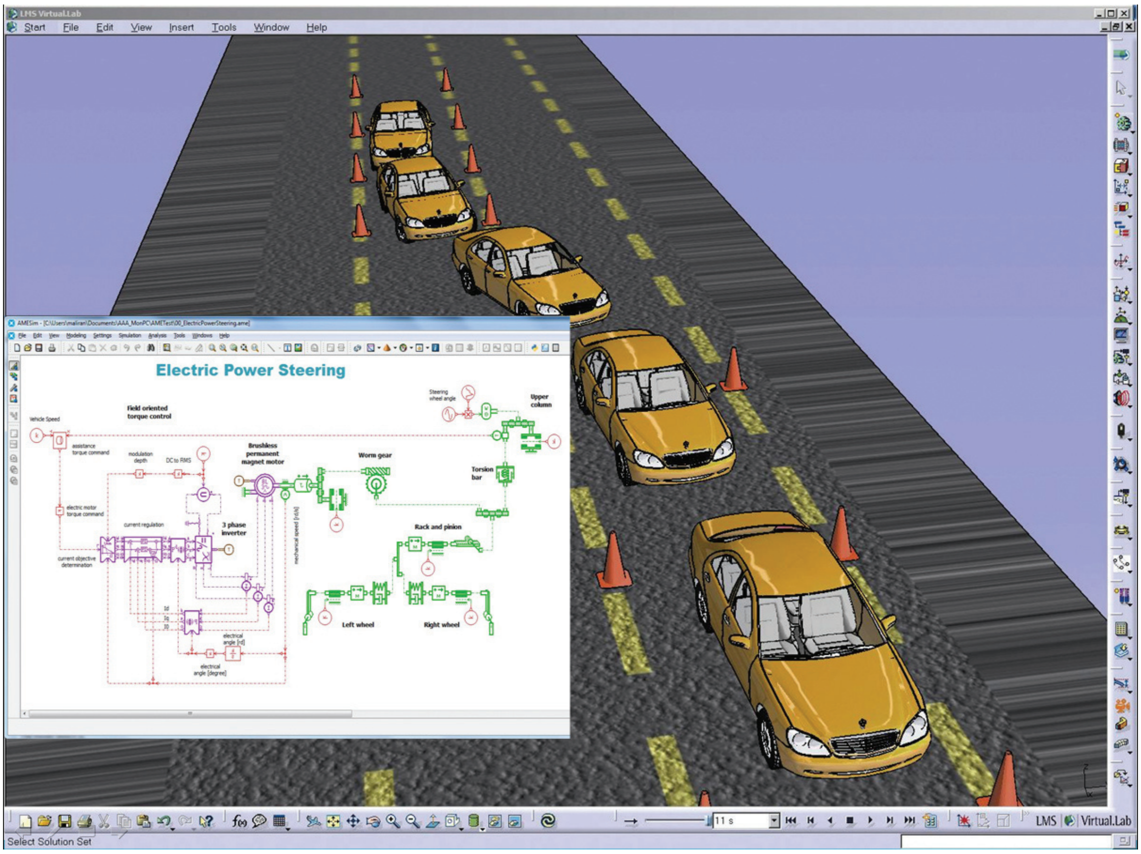
Integrated simulation

EVALUATION OF STEERING SYSTEM PERFORMANCES ON THE ENTIRE VIRTUAL VEHICLE MODEL BY CO-SIMULATION BETWEEN LMS IMAGINE.LAB AMESIM AND VIRTUAL.LAB MOTION

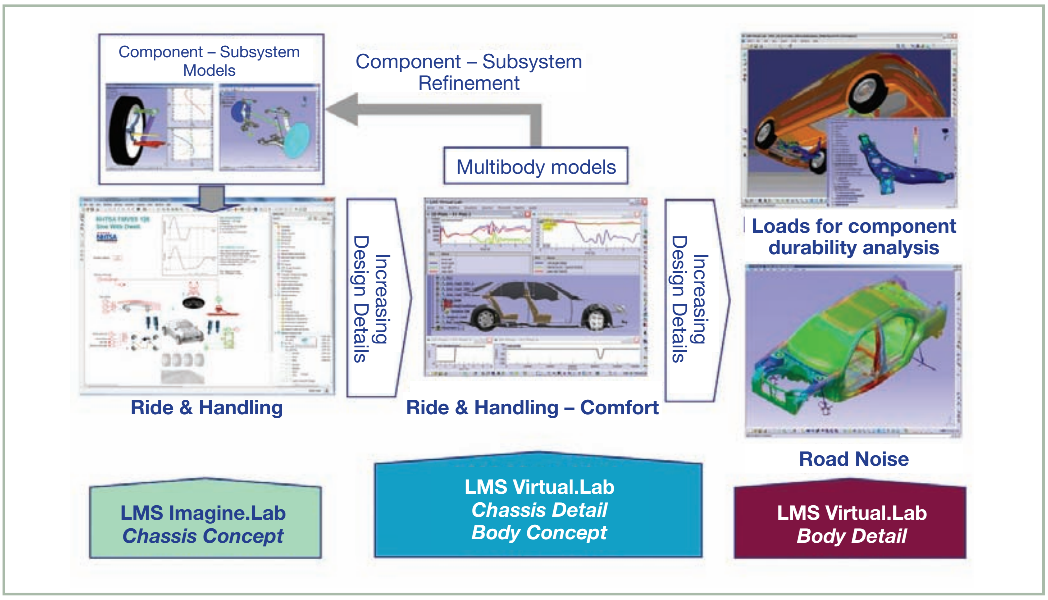


Despite the increased focus on fuel efficiency and environmental issues, much of the attention from customers is focused on vehicle performance – acceleration, braking, cornering, and ride. Those characterizations, which are responsible for the design and development of new vehicles in the automotive industry today, are challenged by questions about the quality desired in the product by the customer: How can the handling of a designed vehicle be guaranteed to match a given target vehicle without compromising comfort or noise performance? How can loads on the vehicle suspension components and the trimmed body be calculated in order to perform fatigue life predictions efficiently and accurately? How can active safety systems, such as ABS or ESP, be taken into account in the routine dynamic simulations with high accuracy? How can a multibody simulation model be made from a vehicle in a modular way, assembling suspensions, steering system, braking system and driveline from separate submodels? How can the ride and handling simulation process on a corporate level be standardized to capture invaluable engineering insight and experience in a knowledge-based environment? And finally, how can reliable and correct loads be predicted in order to guarantee durability performances when prototypes are not yet available?

Furthermore, today's vehicle dynamics engineers are facing all the above challenges while ensuring that safety and fuel economy targets are not hindered. A dedicated analysis solution, including 1D and 3D simulation methodology, will provide invaluable help in the chassis systems and full vehicle design process.

LMS Virtual.Lab Vehicle Motion simulates all types of vehicles' ride and handling behavior, from passenger cars and motorsport vehicles to multi-axle vehicles such as trucks and buses.

Front- and rear-axle suspension models created with LMS Virtual.Lab Suspension can easily be integrated modularly into a full-vehicle model. The time-domain analysis covers everything from the conceptual rigid body model evaluation to high-fidelity model performance with fully trimmed body details and various non-linear effects. The out-of-the-box vehicle solution's predefined templates allow efficient simulations of multiple runs with standardized events, for quarter-vehicle, half-vehicle and full-vehicle events. The available library of predefined vehicle events, including ISO maneuvers, can be extended by any user-defined event. The car can be driven by a kinematic driver or via a path-following control algorithm implemented in LMS Virtual.Lab Motion or the IPG Driver model including complex driver-



SCALABLE 1D AND 3D SIMULATION PROCESS FOR VEHICLE DYNAMICS

vehicle interaction to include human reactions.

LMS Virtual.Lab Vehicle Motion Real Time ensures high-fidelity, full vehicle multibody models, potentially beyond 150 DOF, fully interfaced in any available hardware system.

LMS Virtual.Lab Motion is available in a fully integrated plug-and-play automated solution by using LMS Virtual.Lab Composer and VBA (Visual Basic Applications) journaling and scripting. LMS Virtual.Lab Composer enables customization without coding and contains all the requisite building blocks for accessing core solver technologies with simple drag-and-drop functionality. With VBA scripts, it automates any repeated process, saving time by eliminating highly repetitive tasks, and allowing the optimization of the design.

Accurate tire and road modeling are vital when using motion simulations as input for downstream durability and comfort analysis with LMS Virtual.Lab Durability and LMS Virtual.Lab Noise and Vibration. LMS Virtual.Lab Motion offers a set of tire models dedicated to specific applications going from basic ride and handling analysis at low frequencies up to more complex comfort and durability analysis at higher frequencies: TNO MF-Tire and TNO MF-SWIFT, LMS-LBF CDT tire, and COSIN F-Tire formats are supported.

To provide realistic road load data without the availability of detailed tire models or a digital road surface, LMS has developed a methodology based on Time Waveform Replication (TWR) in cooperation with leading automotive manufacturers. The LMS Hybrid Road Methodology, fully integrated in LMS Virtual.Lab Motion-TWR, translates measured road inputs on a predecessor vehicle to equivalent road load data to be applied in simulation models of next-generation vehicles. Applying the road load cascading process on an unconstrained vehicle guarantees correct load input time histories at all interface hard point locations of any subsystem and component of the suspensions or of the body.

LMS Imagine.Lab Vehicle System Dynamics offers dedicated capabilities to design individual chassis system components (brakes, suspension, steering, anti-roll system and the vehicle itself) and integrate them in a single system model to simulate and validate global chassis control strategies.

With LMS Imagine.Lab Braking System, Power Steering and Suspension and Anti-Roll, LMS provides reliable and accurate models to design robust chassis systems and components (booster, valves, active dampers, etc) early in the process as well as to validate and test control strategies using model-in-the-loop, software-in-the-loop and hardware-in-the-loop. It further gives an understanding of issues specific to each subsystem, such as the noise and vibration behavior of braking systems, shimmy phenomenon of power steering systems and improved damper design versus cavitation.

In addition, LMS Imagine.Lab Vehicle Dynamics offers a comprehensive vehicle dynamics library for real-time simulation or real-time hardware, including parametric functions to modify the shape of kinematic tables in order to optimize the vehicle behavior.

Efficiency in simulation can be achieved from the correct application of 1D physics-based and 3D geometry simulation. The unique combination of LMS Virtual.Lab Motion and LMS Imagine.Lab AMESim allows an efficient scalable simulation process. In LMS Imagine.Lab AMESim, models can be built for chassis concept analysis, based on libraries for suspension components (elasto-kinematic representation). Many different layouts and variations of suspensions can be studied for many different vehicle configurations – for instance, loading. As design details become available for the actual suspension, and body concept is available, one can further transit to a 3D model in LMS Virtual.Lab, expanding also the realism of simulation to ride comfort – by taking into account flexibility of subframes, vehicle body, and appropriate tire modeling.

Direct co-simulation between LMS Imagine.Lab AMESim and LMS Virtual.Lab Motion enables complex chassis interactions to be tackled, such as those between mechanical and hydraulic systems, or analyzing the shimmy phenomenon or the steering handling.

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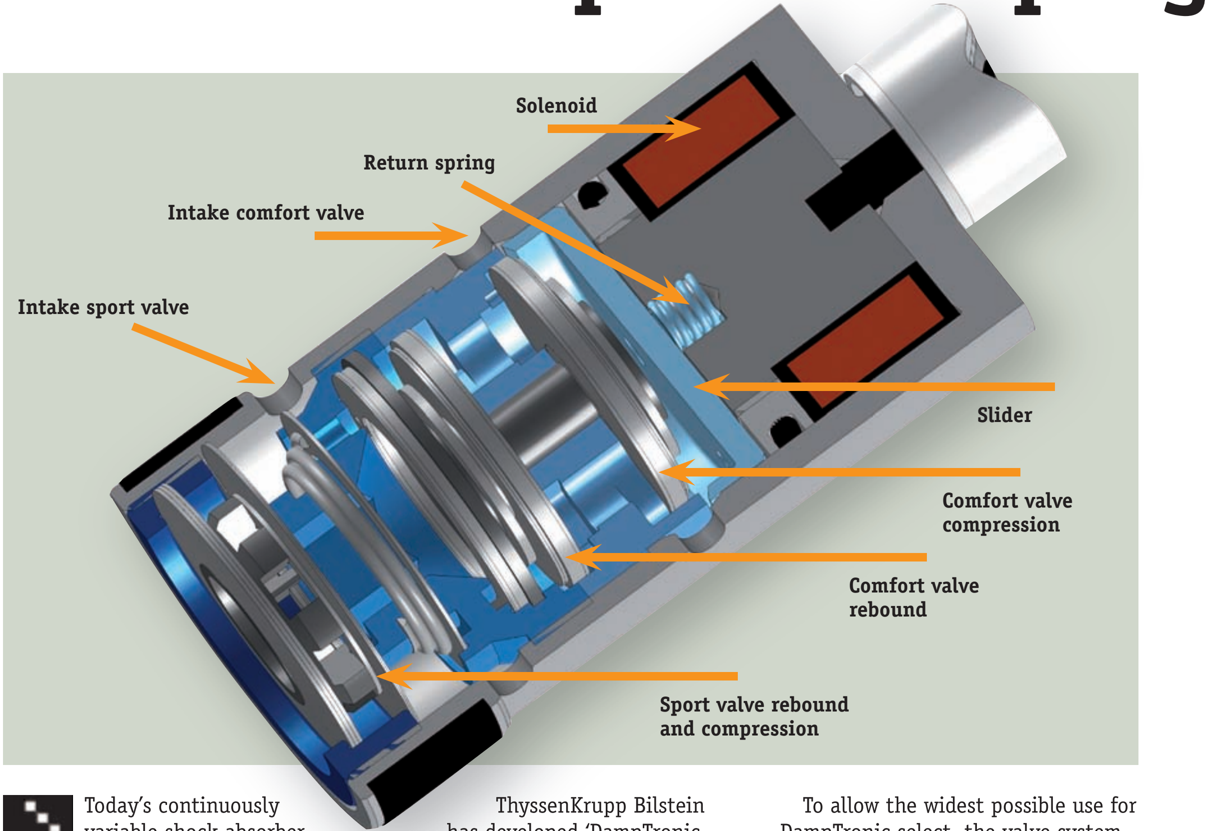
Low-cost adaptive damping

RIGHT: **DAMPTRONIC SELECT VALVE DESIGN**



Today's continuously variable shock absorber systems consist of shock absorbers, various sensors that measure the motions of the body and the wheels, and a control unit to control the shock absorbers on the basis of specific algorithms. But the high cost and complex integration of adjustable shock absorber systems restricts their wider use. For broader application, the system costs need to be drastically reduced while maintaining adequate functionality.

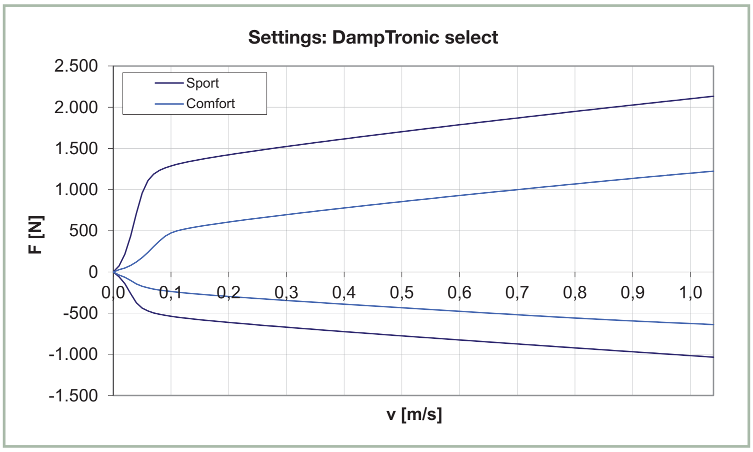
ThyssenKrupp Bilstein has developed 'DampTronic select', a low-cost adjustable system that is positioned between the established adjustable shock absorber systems and conventional shock absorbers. The key component of the system is the DampTronic select shock absorber, which can be switched between a comfort and a tighter sport characteristic via a dash-mounted button. The system needs no sensors, and control unit requirements are minimized.

To allow the widest possible use for DampTronic select, the valve system had to be adapted to the common shock absorber sizes. According to the demands of the market there are valves with 32mm, 36mm and 46mm valve diameter available.

On many shock absorbers, integrated rebound springs lead to the problems of length design, as in addition to the block length of the spring, the length of the valve housing has to be integrated into the shock absorber. To avoid reducing stroke length with given shock absorber sizes, a technically acceptable minimum build length was targeted. By integrating all functional elements to save space, a length of 51mm was achieved. Compared with conventional pistons, this means an acceptable length increase of just 20mm.

The two-stage valve in the DampTronic select system allows the driver to choose between the comfort characteristic and a sport characteristic at the touch of a button. Although the system is preferably operated in comfort setting, both shock absorber characteristics can be fully tuned

RIGHT: **THE RANGE OF DAMPING AVAILABLE FROM THE SYSTEM**



in the same way as conventional shock absorbers. This allows the characteristics to be tailored to specific vehicle requirements without sacrificing responsiveness, ride comfort, or driving dynamics.

Against the background of the current CO_2 debate, the power requirements of all electrical systems integrated into the vehicle are of major importance. This was addressed by optimizing the design of the electromagnetic drive under the given parameters. The magnetic coil is designed in such a way that, when set to the comfort characteristic, an input of less than 1W per shock absorber is required. Continuously adjustable shock absorbers normally require an input of 5-10W. When the power is switched off, the shock absorber switches to the sport setting and operates passively, that is, with no further energy input.

In addition to direct power consumption, part weight also has a major impact on a vehicle's total CO_2 emissions. In order to keep the weight increase to a minimum compared with a conventional solution, the adjusting valve was mounted directly on the piston rod. This arrangement makes it possible to use the tube body of the conventional shock absorber without the need for modifications. From a hydraulic viewpoint, this arrangement is also preferable to solutions where the valve is mounted on the side of the shock absorber tube. The compact size of the valve results in a weight of just 80g more than a conventional shock absorber.

In terms of system costs, the DampTronic select system is less expensive than the established, complex adjustable shock absorbers because of the elimination of the sensors and the simplification of the control unit and the shock absorbers. Functionality has been reduced from continuously adjustable to two switchable characteristics. To meet target costs, the valve unit was engineered on a design-to-cost basis. Compared with a continuously adjustable shock absorber, the cost reduction for the DampTronic select shock absorber is about 40%. The DampTronic select system, comprising control unit and shock absorbers, is about 70% less expensive.

The final valve design was developed by taking into consideration the specified targets for packaging, characteristics, power requirements, weight, and costs.

The DampTronic select valve contains a comfort valve and a sport valve. A solenoid allows the comfort valve to be connected hydraulically in parallel with the sport valve, which sets the comfort characteristic.

In the upper part of the valve there is the solenoid; when energized, the magnetic force pulls up the slider positioned below it to open the flow channel through the comfort valve. According to the hydraulic network the main flow passes this valve and the soft setting is generated. The comfort valve can be tuned in a similar way to conventional shock absorber valves, that is, the hydraulic resistances on the rebound and compression sides of the valve are adjusted using suitable preload elements and bypass channels. As this is the setting that is mainly used during normal driving, a wide range of tuning components is available.

When the solenoid is not energized, a return spring presses the slider onto the valve seat to interrupt the oil flow. In this mode, the comfort valve is switched off and the complete oil flow goes through the sport valve, which determines the hard setting. The sport valve is located at the lower end of the DampTronic select valve. Its characteristics are set by a valve stack that works in both directions. Overall, the tuning parameters provide broad scope for adapting the DampTronic select valve to the requirements of a wide range of vehicles.

In the DampTronic select adjustable shock absorber, ThyssenKrupp has developed a robust, low-cost system that offers drivers the opportunity to choose between a soft, comfortable and a tighter, sporty suspension setting at the touch of a button. Compared with a continuously variable system, the DampTronic select system features a simplified adjusting valve and eliminates the need for sensors and a complex control unit. The series launch for the first applications will be in 2012.

CLOSE-UP CUTAWAY OF THE DAMPER BODY (LEFT)**, AND THE UNIT IN FULL** (BELOW)

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Quote ref VDI 006

Advanced power steering

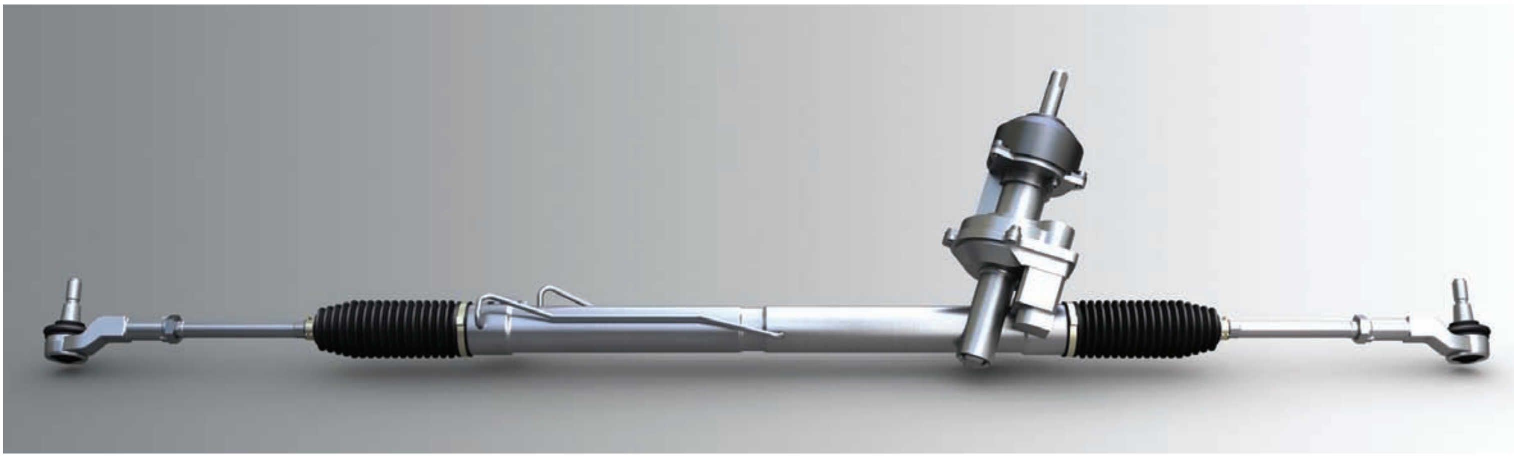


FIGURE 1 (ABOVE): **TEDRIVE'S INTELLIGENT HYDRAULIC STEERING ASSIST**

FIGURE 2 (BELOW RIGHT): **VARIABLE BOOST CURVE CONTROL**

Demands on steering systems now exceed the simple functionality of steering assistance. Additional safety and comfort features like automatic parking, lane keeping aid, trailer stabilization, variable boost curve (see Figure 2), superimposed steering angle/torque, or need-based controlled power consumption, are ever more in engineers' scope. The intelligent Hydraulic Steering Assist (iHSA) developed by tedrive Steering is a steering system with a functional scope analogous to electromechanical power steering (EPS).

The objective of tedrive was to develop a hydraulic steering system featuring a scope of functions analogous to those of an electric steering system, including driver-independent torque overlay, while simultaneously achieving CO_2 savings. For this purpose, reliable technologies were to be applied, namely a rotary valve, a steering gear with a tedrive steel housing design, and proven manufacturing processes.

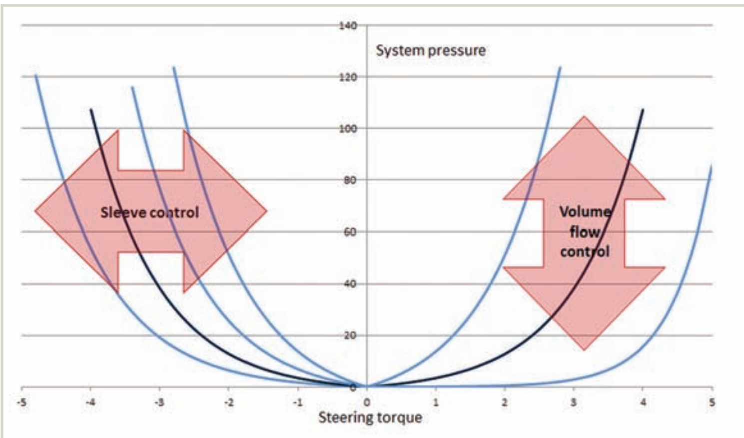
The main engineering objective was to be able to provide comfort and safety functions in vehicle classes such as SUV, LCV, medium commercial vehicles, and trucks through the development of iHSA.

In these vehicle segments in particular, professional drivers could be supported by driver assistance systems. In 2009, the EU passed Directive No. 661/2009, which specifies the installation of lane departure warning systems in new commercial vehicle types of the categories M2, M3, N2 and N3 from November 2013 on. After this date, national authorities can no longer issue registrations for such vehicle types if they are not equipped with lane departure warning systems in full compliance with the Directive.

Thanks to iHSA technology, the hydraulic steering assist system is able to provide the kind of comfort and safety functions that have so far only been achieved by EPS in lower vehicle segments. In its iHSA system, tedrive has succeeded in significantly improving the performance parameters of hydraulic steering systems and in developing a viable counterpart to EPS.

At present, electromechanical steering systems can only apply limited toothed rack forces, even with extensive manipulation of the on-board energy management system, whereas tedrive's iHSA is distinguished by its ability to exert much greater toothed rack forces without having to make any changes to the energy management. The iHSA has also received an 'ASIL-C' safety rating from TÜV Süd. For OEMs, this represents considerable safety-related cost-savings compared with EPS systems, which involve much higher expenses due to their 'ASIL-D' rating.

As a result of a design solution, it is possible to limit the difference angle mechanically. Depending on the torsional stiffness of the torsion bar, the maximum superimposed torque can be 4-5Nm. The advantage is that an actuator's faulty superimposed torque can be overridden by the driver at any time. Compared with an EPS, the iHSA is considerably more tolerant of errors. In case of an EPS, if an error occurs, it is not possible to superimpose such



a large steering moment that the result is a 'self-steer'.

As already mentioned, the advantage of the override by the driver means that the iHSA is categorized as an ASIL C, compared with an EPS's ASIL D. Therefore, the functional safety processes do not have to fulfill the same requirements as an EPS and thus involve lower development costs. Depending on the functional portfolio offered with iHSA, the safety requirements can even be lowered toward ASIL B.

The engineers at tedrive have transformed the hydraulic steering system into a semi-active assist system that includes all the functions of an electromechanical steering system. The hydraulic solution is variable and independent of front axle loads. Further benefits include optimized mounting dimensions, cost, and design advantages for platform strategies. As in EPS systems, the addition of a servomotor with electrical actuator to a hydraulic steering system yields improved comfort and safety functions through torque overlay. But keep in mind that the required hydraulic power is still supplied from the flow-controlled pump. The electrical actuator simply controls the hydraulic flow through the steering system and therefore needs very little electrical power. The sizing of the electrical actuator is identical for all vehicle segments. A truck application requires the same electric actuator as a small car.

A conventional hydraulic steering system also provides a useful volume flow while the system is idling, for example, when the vehicle is moving straight ahead. At this point, energy is converted unnecessarily. Electric steering systems and pumps avoid this by controlling the provision of power according to the requirements. However, both systems are restricted in the amount of power they can take from the on-board power supply. For higher axle loads, for example in the commercial vehicle or truck segment, high levels of steering power are required. Only belt-driven steering pumps can be used. Through the use of an electrically controlled orifice in a constant or variable displacement pump, it is possible to control the power consumption of a hydraulic steering system as required and considerably reduce losses. Today, these pumps have similar levels of efficiency as electric steering pumps.

Slow steering angle velocities (< approximately 100°/sec) can also be supported electrically, when keeping the pump flow at its lowest level, therefore minimizing the pump losses and simultaneously obtaining the correct steering feel with the actuator. While the steering system is idling, the pump delivers approximately 2 l/min. A requirement of, for example, 10 bar steering assistance would be acknowledged by raising this to approximately 4 l/min (see Figure 3).

The difference in power dissipation in these two points of operation is approximately 100W. If the increase in the volume flow is compensated for by sleeve control in order to maintain the steering feel, the power consumed by the actuator is approximately 10W. The steering system thus consumes approximately 90W less power (see Figure 4).

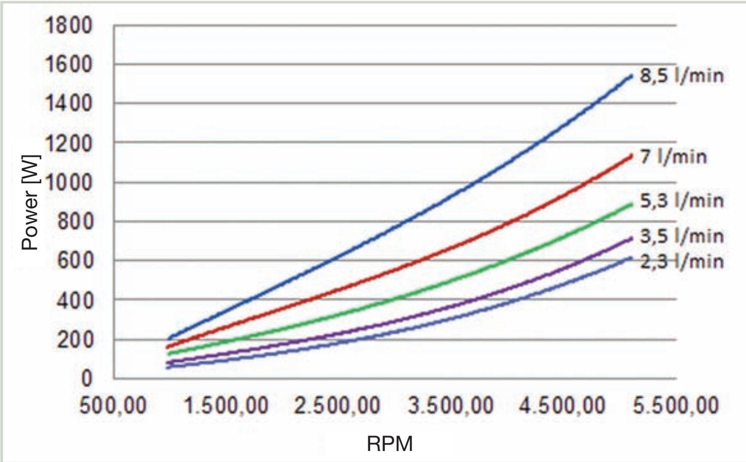


FIGURE 3 (LEFT): **POWER CONSUMPTION FOR DIFFERENT PUMP FLOW RATES**

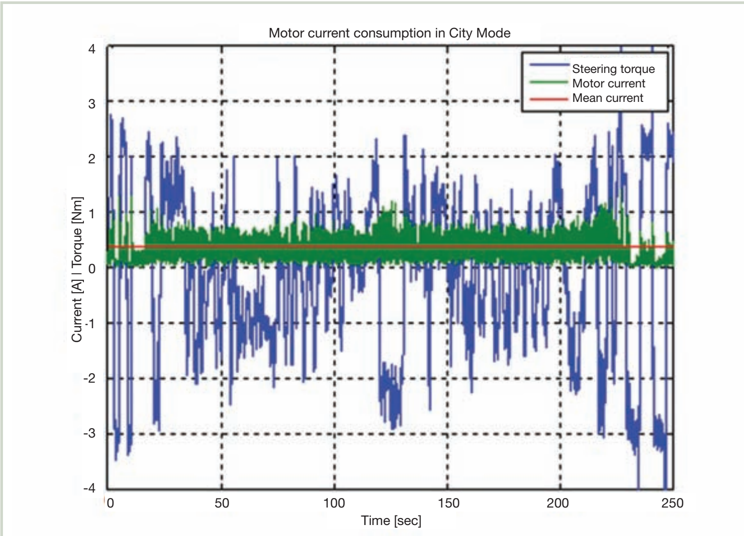


FIGURE 4 (BELOW LEFT): **BOOST COMPENSATION BY SLEEVE CONTROL**

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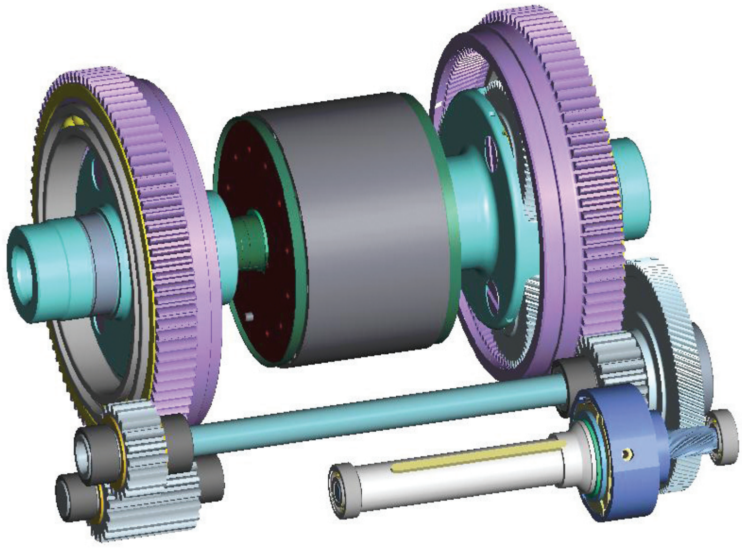
Electric torque vectoring

RIGHT: **THE eAWD SYSTEM CONSISTS OF TWO ELECTRIC MOTORS, ONE PROVIDING PROPULSION TORQUE TO THE REAR WHEELS AND THE SECOND ADJUSTING THE DIFFERENTIAL TORQUE LEFT TO RIGHT BETWEEN THE REAR WHEELS**

BELOW: **BORGWARNER'S eAWD CONCEPT COMBINES AWD AND HYBRIDIZATION**



To reduce CO_2 emissions while increasing traction, stability, and performance, BorgWarner has developed an electric all-wheel drive (eAWD) concept that combines AWD and hybridization in one small, robust new package.

Vehicles with conventional mechanical AWD systems can provide increased traction, better turn-in, and a more stable ride than, for example, front-wheel-drive vehicles. The eAWD system solves a dilemma facing electric and hybrid vehicle manufacturers: how to provide all-wheel-drive traction and stability without adding the driveline losses that increase emissions and reduce fuel economy.

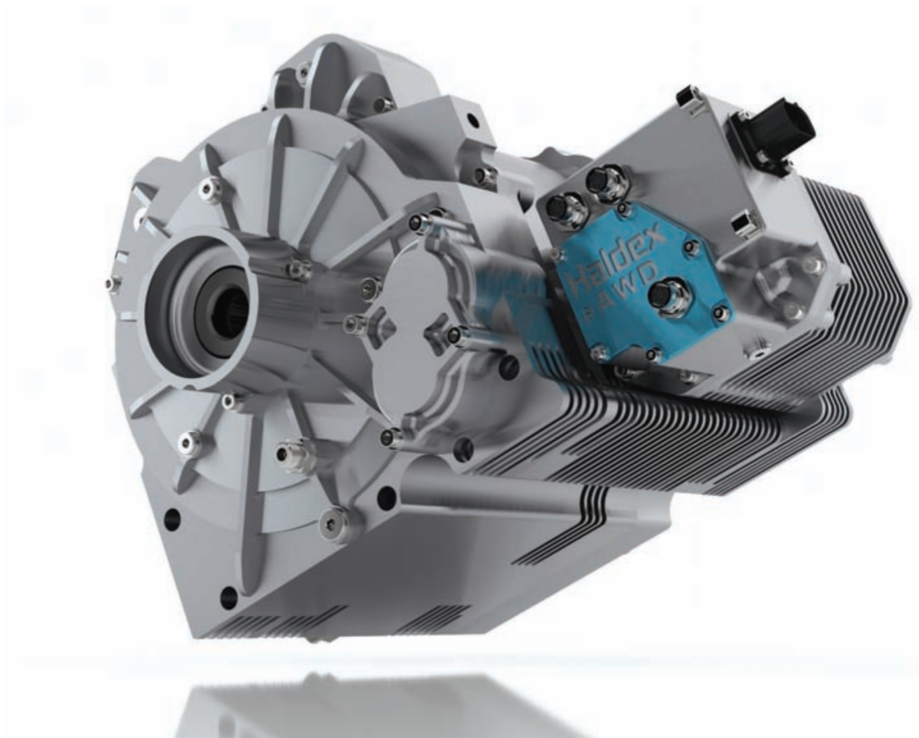
In order to satisfy the increasing needs of customers, BorgWarner's electrically driven AWD system with built-in torque vectoring functionality can reduce fuel consumption by as much as 20% compared with conventional mechanical all-wheel drive systems. This can be further improved with higher installed power of the system or the use of recuperated brake energy. By upgrading the propulsion motor, the system can also be used in plug-in hybrid or battery-powered electric vehicles. In addition, the torque vectoring concept can be applied in a mechanical driveline where the propulsion motor is replaced with a conventional driveline.

The eAWD system consists of two electric motors, one providing propulsion torque to the rear wheels via a planetary gear arrangement on each side. The second electric motor adjusts the differential torque left to right between the rear wheels. Both motors can be dimensioned for the required traction torque from eAWD up to pure electrical drive and the torque vectoring motor is dimensioned for the required amount of torque.

One major benefit of the system is that the torque vectoring motor works on a balance shaft that is not rotating when there is no differential speed between right and left side. Therefore vectored torque can be applied independent of vehicle speed, delivering more stability with excellent vehicle dynamics and the electric motor can be kept small as it works only with the differential speed between the wheels. As the eAWD system is always active, no driver intervention is needed, making the combination of exciting performance and improved safety effortless.

In a bid to be cost effective, BorgWarner has chosen an oil cooling concept integrated with the lubrication system. For high-power versions the system can be complemented with air- or water-cooled heat exchangers.

The new system can also be easily used in plug-in vehicles or purely electrically driven vehicles by upgrading the propulsion motor. Torque vectoring is an optional function for improving both stability and vehicle dynamics.



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Quote ref VDI 008

Steering testing

Rapidly evolving electronic steering systems provide new opportunities for vehicle developers to improve vehicle efficiency, handling, comfort, and safety, enhancing the overall driver experience.

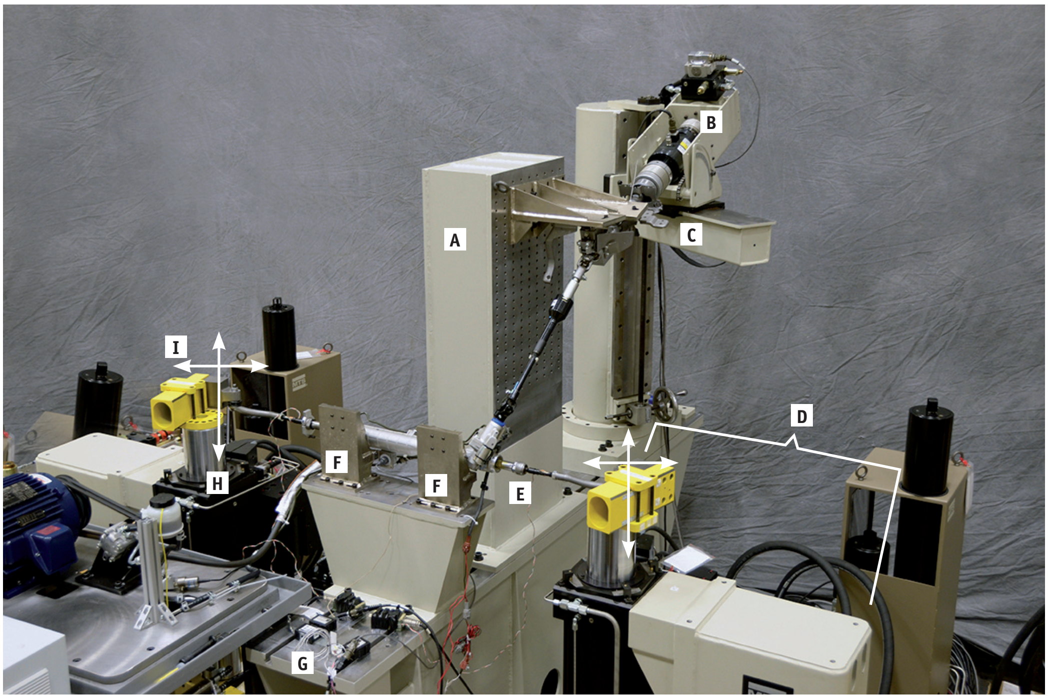
The complexity of these new systems and their interactions with other vehicle subsystems, however, present many new difficulties throughout the vehicle development process, from characterization to full vehicle tuning and evaluation.

Purely hydraulic steering systems have simple tuning parameters and risks that are well understood by vehicle development teams. Solutions to help vehicle developers characterize and evaluate these systems are readily available today and verification can easily be done on the test track.

The transition from hydraulic to electronic steer technology brings many additional tuning parameters, technologies, and risks to the vehicle development program. New tuning parameters include compensation for complex conditions such as wind pull and road crown. New technologies include incorporating the electronic stability control system to alter steering gear ratios and steering assist levels, active steering systems, and collision avoidance systems.

These new parameters and technologies pose risks to the vehicle developer because they feature hard-to-model components, add an array of new fault conditions to evaluate, and include complex vehicle subsystem interactions that cannot be evaluated with standard tools and test methods.

In addition to improving vehicle efficiency and enhancing driver experience with new electronic steering technologies, vehicle development teams are also challenged with reducing vehicle development costs and time, and eliminating warranty-related costs. This places constraints on the vehicle developer to be at the test track earlier for validation work, to shorten the validation cycle time, and to prevent work being repeated late in the development cycle.



MTS STEERING TEST SYSTEMS ARE AVAILABLE IN THREE-CHANNEL OR FIVE-CHANNEL CONFIGURATIONS.
LEGEND:
A: STEERING COLUMN FIXTURE
B: STEERING INPUT ACTUATOR
C: 5-DOF STEER HEAD
D: TIE-ROD LOADING FIXTURE
E: TIE-ROD FORCE MEASUREMENT
F: RACK FIXTURING
G: SPECIMEN TEST FRAME WITH LONGITUDINAL T-SLOT
H: VERTICAL TIE-ROD INPUT ACTUATOR
I: LATERAL TIE-ROD INPUT

To help vehicle developers keep pace with these rapidly advancing technologies and development constraints, MTS Systems Corporation has developed the mechanical Hardware-in-the-Loop (mHIL) Steering Test System. Available in three- or five-channel configurations, this system extends simulation by placing the physical steering system inside the loop of a real-time full-vehicle CAE model.

Engineers 'drive' the car in a virtual environment while subjecting the physical steering system to mechanical forces and motions, making it possible to characterize and perform full-vehicle evaluations of new electronic steering systems from a single software interface. Because inputs are highly repeatable, the system simplifies the management of multiple tuning parameters associated with electronic steering systems, regardless of complexity.

The mHIL Steering Test System provides greater insight into subcomponent and vehicle behavior before the full vehicle prototype becomes available. Design modifications are much less expensive and time-consuming at this stage of vehicle development, enabling vehicle developers to control development costs and add the latest steering system technologies to more models.

Vehicle development engineers also benefit from a wider array of quantitative test data points, many of which are not available through typical track testing. All of this leads to more robust prototypes and less rework at the proving ground stage.

MTS's mHIL Steering Test System is in use by a major Japanese OEM, which has demonstrated correlation to actual track testing for subsystem characterization and overall vehicle evaluation. Plans are underway to deliver a system to a North American OEM, and potentially several other manufacturers worldwide.

MTS also offers mHIL solutions for suspension and many other vehicle subsystem applications.

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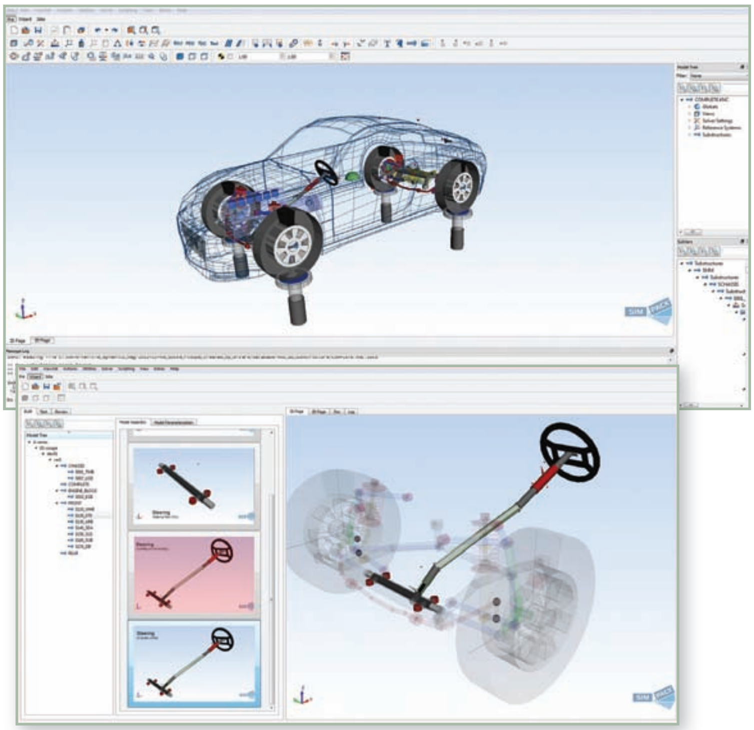
New simulation release



RIGHT: **SIMPACK 9 APPLICATION WIZARD FOR AUTOMOTIVE ALLOWS THE USER TO CREATE A MODELING, ANALYSIS, AND POST-PROCESSING ENVIRONMENT**

SIMPACK has been working closely with its automotive customers for more than 20 years to deliver high-fidelity simulation for their prediction of vehicle ride, ride comfort, and engine and driveline noise and vibration.

Now a major step forward has been made possible with the release of SIMPACK 9. Its features have been developed together with SIMPACK customers to provide a variety of benefits from new modeling features, ease of use, performance, and deployment strategies. Included in this article are just a few highlights of these new features.

SIMPACK's customers have seen the value of including more details in their simulation to understand the coupling effects of these new, complex systems. In SIMPACK 9, modeling strategies for connecting and managing the ever-increasing variety of component and subsystem configurations have been included. In one single model users can easily select components and subsystems without the need for duplication of the model. It is also easy to select parameter variation for each component or subsystem in the vehicle, driveline, or engine.

Simulation performance is always a consideration when looking at increasing the fidelity of simulation models. In SIMPACK 9, performance features have been implemented in a number of ways. For modeling, there is the speed of editing and viewing the topology of the model. This is very effective when including subsystems of SIMPACK models and the large control systems in MATLAB that are so critical in today's vehicles.

The SIMPACK solver is well known for its stability and speed of solution. Now SIMPACK has taken another major step forward with the inclusion of new solver performance strategies that include support for multiprocessor systems at the level of both the laptop user and large-scale multiprocessor systems.

Typically, with complex simulation and analysis programs, the value of these simulations is often limited by the number of dedicated users and their ability to relate the simulation results to the general engineering public in their company. A means of supporting the casual user with a complex modeling problem has been included in SIMPACK 9. Called SIMPACK Application Wizard, it allows the user to create a modeling, analysis, and post-processing environment for many types of design applications.

While it is not limited to vehicle modeling problems, it has been especially targeted for use in this area. The casual user can work with a standard SIMPACK user to create an application-specific interface in SIMPACK that allows the casual user to select the critical model parameters for modification, and to create selectable load cases to run and connect these two parts with a design scenario that is included in the wizard interface. The casual user can then follow the design process and make the appropriate changes to the model, select the simulation process, and then plot out the results with formatting that is appropriate for the design process (*see image*).

This is a major step forward for easily supporting the scenario where a casual user needs complex model data, but has no idea of what parameters are appropriate for modification and the range for reasonable values. Too often, the complexity of simulation tools has limited the casual user to use low-fidelity solutions that compromise the quality of the resulting output and design decisions. This functionality allows the SIMPACK customer to focus on new challenges and deploy their typical modeling and analysis scenarios out to the general user community.

SIMPACK 9 also includes new and improved interfaces for CAD, FEA models, tire models, controls, hydrodynamic bearings, biomotion, etc. These interfaces not only improve ease of use, but also increase functionality.

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Quote ref VDI 010

Innovative testing

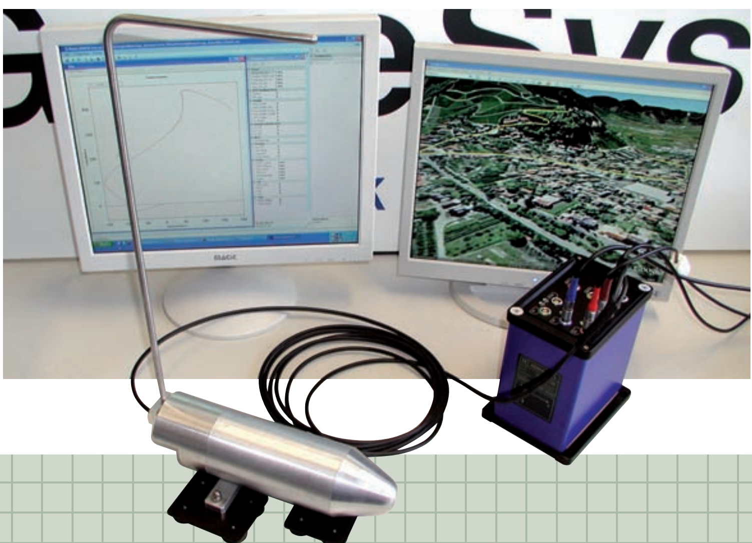
LEFT: **ADMA-G: GYRO SYSTEM FOR DYNAMIC TESTING WITH GPS SUPPORT**

BELOW LEFT: **ADMA-PP: POST-PROCESSING SOFTWARE FOR ROAD TESTS**

Accurate determination of all movements is an important requisite during vehicle dynamics testing. The ADMA (Automotive Dynamic Motion Analyzer) Gyro system has been specially developed for such applications. The ADMA-G system consists of three optical gyroscopes, three servo accelerometers and an internal GPS receiver for absolute positioning with WAAS or RTK-DGPS correction. A 32-bit DSP processor unit continuously calculates the speeds and position in all three spatial axes, as well as pitch, roll, heading and side slip angles, from the sensor signals and external information.

Advanced driver assistance systems (ADAS), such as where a cruise control system also measures the distance to a vehicle in front and reduces speed as necessary, must be evaluated during the development phase. For the validation process in road trials, a test system is used that was developed by GeneSys Elektronik in cooperation with Dewetron and TÜV Süd Automotive.

It is notable that this system, consisting of a combination of a GPS system and the ADMA inertial system, registers the positions and movement of multiple vehicles synchronously. In addition, further data (such as video data, data from the CANbus of the vehicle or other analog or digital data) can be synchronously registered and displayed. At the same time, the data of all the vehicles is synchronized. Other applications such as lane departure warning (LDW) and forward collision avoidance (FCA) are also addressed.



Electrical/electronic systems in automobiles must operate safely. In order to prove the functional safety of ABS/ESP systems during road trials according to ISO 26262, a number of situations are simulated; for example, a sensor failure. This is a measure to examine the extent to which the vehicle can still be controlled in such a case. Dewetron is currently introducing a new test system for such trial runs, which displays all vehicle values, exact position data and the internal parameters of the ABS/ESC system.

The test system consists of a DEWE-511 data recorder and a special plug-in for the DEWESoft 7 data acquisition software. GeneSys Elektronik's ADMA system is also used to obtain exact vehicle position and movement measurements. With a combination of GPS and inertial sensors, the system delivers very precise position data with an accuracy of a few centimeters.

One prerequisite of driving tests as part of vehicle development is to precisely determine the vehicle's position. In such applications, the ADMA delivers optimized and highly precise data. To ensure precise positioning even under difficult GPS reception conditions, GeneSys now presents the new ADMA-PP post-processing software, which allows optimization of ADMA data recordings and inclusion of GPS correction data after the test drive.

The software's core is a Kalman filter that perfectly combines GPS and inertial data. While the real-time option continues to be provided by the ADMA system, off-line calculation has decisive advantages. The easy-to-use package is completed by an auxiliary module with a barometric altitude sensor allowing accurate measurements of critical height-related data.

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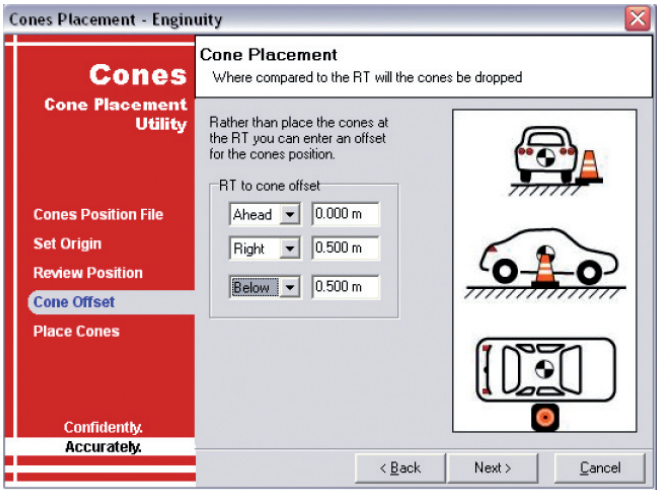
Cone placement software

RIGHT: **PLACING CONES ON A TEST TRACK WITH THE NEW OXTS CONE PLACEMENT FEATURE**

Repeatability and accuracy are of the utmost importance when performing vehicle dynamics tests. OxTS has recently launched a useful cone placement tool for its RT measurement systems. This new, ingenious feature makes it easy and quick to lay out cones accurately on a proving ground.

If users need to place some cones for a specific test maneuver, they can do that now with maximum precision. The cone placement tool also allows users to lay out exactly the same course over and over again. This is especially useful when benchmarking cars or assessing the ride and handling characteristics of different car models, where the same course must be used again, but the cones cannot be left on the test track permanently. The cone placement tool also allows customers to use exactly the same course again in a different location or on a different test track.

Using the cone placement feature of Enginuity is simple and quick. The positions of the cones are loaded from a simple CSV file. Users can either create their own cone layout or use one of the OxTS templates. OxTS has created a library of cone placement files so that it is easier and much quicker to lay out cones according to fixed patterns. Currently there are CSV files for circles, slaloms and lane-changes.



BELOW: **CONE PLACEMENT SOFTWARE IS USED TO CONFIGURE THE LOCATION ON THE VEHICLE WHERE THE CONES ARE DROPPED**

With the RT inertial and GPS navigation system installed in the vehicle, the user chooses a location on the outside of the vehicle where the cones will be dropped and their positions accurately measured. Once the CSV file containing the coordinates of the cones is loaded into Enginuity, the software will guide the driver to the location where the cone can be dropped. Using a tape measure, small offsets from the car's position to the correct cone location can be compensated for before moving on to the next cone. A detailed window shows the position of the cone as the driver approaches the spot where it is to be placed. The driver can use the overview window to track the overall progress.

Using Google Earth, the position of the cones can even be visualized before they are placed. This can be useful for planning the cone layout before starting to drive.

With the new cone placement tool, OxTS has released yet another useful feature for the RT inertial and GPS measurement systems. The R&D department at OxTS is constantly working to enhance the functionality of its products for automotive testing. A constant flow of product improvements and software updates keeps OxTS measurement systems a step ahead of the market.

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Human-in-the-loop

ABOVE: **QUT – CARRS-Q ADVANCED DRIVING SIMULATOR (AUSTRALIA). DRIVER PERFORMANCE STUDY**

Over the past 20 years, the role of the mechanical engineers involved in vehicle dynamics testing has drastically changed. The software generates the equations and the source code, the simulation packages include standard tests, and the vehicle dynamics model directly imports data from test benches or highly detailed FEM codes. Today, the main task for these engineers is to develop systems that will improve drivers' safety, comfort, and fuel efficiency.

This leads to complex car systems that require thorough validation test programs, using a large number of well-defined use cases, in order to achieve acceptable reliability.

But ultimately the most efficient and unpredictable system behind the steering wheel is a human driver. And this makes a lot of difference. Are they able to cope with each and every piece of haptic, visual, and audio information that is supposed to improve their safety? Can they handle the car and react properly when a new alarm is suddenly activated in a critical situation? Are they ready to accept the usage for which their car has been optimized?

The driveability concept is no longer based solely on the chassis tuning, but on everything that will impact the driver's perception of the car's handling. By underestimating this factor, the drawbacks may appear only during the late pre-series tests, leading to additional development costs, delayed time to market, and possibly program cancellation.

In many instances, experiments conducted on a driving simulator can be of great help to identify these issues at the early stages of the design process.

For example, because of the advanced chassis control features, the advanced front-lighting system (AFS) can provide an extremely efficient stabilized headlight system. But the light beam motion is a precious information source for the driver as he does not really see the surrounding landscape. By artificially controlling it, the car may mislead the driver, causing incorrect situation evaluation.

Another point to note is that features such as EPS with crosswind compensation, ACC, and lane-keeping assist may lead to a long-term habit: the driver recalibrates himself to the assistance when it is used for more than 30 minutes. When the system switches off the assistance, the driver is not necessarily ready to handle the resulting vehicle behavior. Different solutions are available to cope with this issue, such as changing the assistance level, the ergonomics or the vehicle dynamics criteria. Such a decision has to be made during the pre-design phase.

Involved for 20 years in human-in-the-loop engineering by developing driving simulators for car manufacturers and research labs, Oktal provides turnkey systems and SCANeR software packages that help engineers facing these challenges to include the human factor in the design process. The company's services help answer the important question: is the design really human-proof?

BELOW LEFT: **A DRIVING SESSION TO EVALUATE AN ACTIVE HEADLIGHT STABILIZATION BY COUPLING AFS AND ACTIVE CHASSIS CONTROL**

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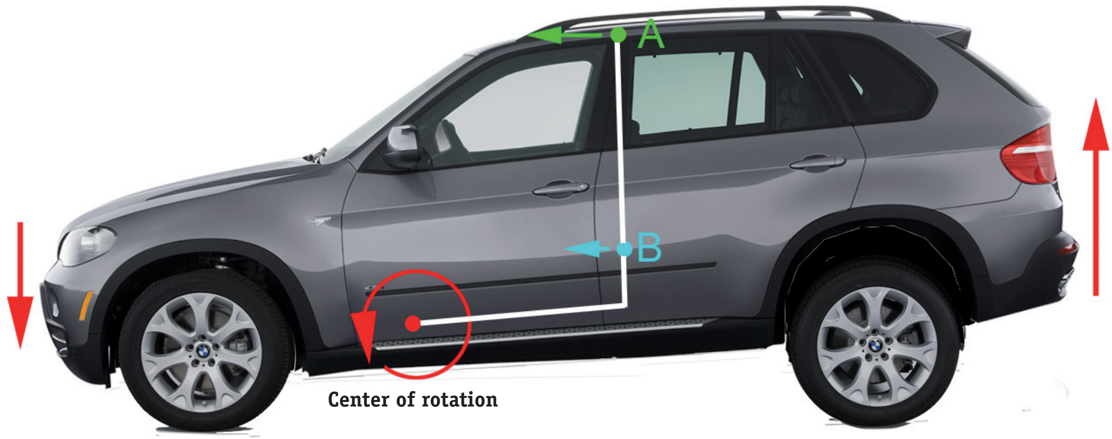
Accurate brake testing



RIGHT: **THE SPEED OF POINT A WILL BE GREATER THAN THE SPEED OF POINT B DURING THE EARLY STAGE OF BRAKING, DUE TO THE VEHICLE PITCHING FORWARD. USING A VBOX WITH BRAKE TRIGGER ELIMINATES THIS ISSUE**

Manufacturers, tire developers, and brake component producers are on a constant quest to reduce stopping distances and improve vehicle stability. As capability improves, the testing systems required to evaluate them must be accurate to less than 2cm.

The usual process for these tests, undertaken in carefully controlled conditions at a test track, is to warm up the tires and brakes in a series of maneuvers, before accelerating to above the desired starting speed and placing the transmission into neutral. Once the desired speed is reached the brake pedal is activated as fast as possible (sometimes using a brake robot). This is repeated a number of times.

Tests can also involve braking while the opposing sides of the vehicle are running on different surfaces – called 'split-µ' – or braking while cornering. As the technology becomes more advanced, performance improvements become more subtle and engineers need increasingly precise distance measurements.

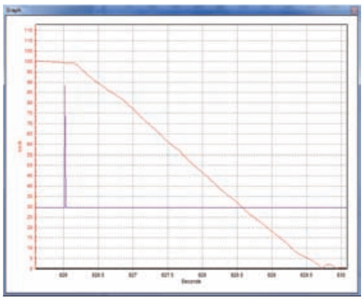
However, high stopping-distance measurement accuracy is irrelevant if you are unsure about when the test actually starts, and at what speed the vehicle is traveling. It sounds like an obvious question, but it uncovers an interesting problem. During the transient period of the brake stop, the car is undergoing a rapid change in pitch angle, making it very difficult to define the actual speed of the vehicle. During the pitching phase, the vehicle is rotating around the center of pitch, which is difficult to determine and differs from the center of gravity. The speed differential around the vehicle may only be less than 1km/h, but if you are using a speed to trigger the braking measurement this can lead to an error of more than 1m!

It is therefore vital to pick a start speed that occurs before or after this transient period, otherwise the distance measured will be inconsistent and certainly not comparable between vehicles. Using Racelogic's brake trigger with a VBOX GPS datalogger eliminates this problem, as it ensures that the test starts before this problematic period. To ensure high accuracy, Racelogic's VBOX scans the brake trigger, marking the point at which it happens relative to GPS time to within a few nanoseconds.

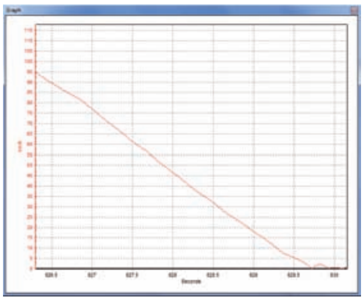
But is GPS actually accurate enough to measure brake distance? Standalone GPS position will lead to inconsistent results, but by using the Doppler effect on each satellite to measure velocity 100 times a second, the distance traveled can be measured with centimeter accuracy. This has made GPS the most popular tool in evaluating brake performance, and Racelogic's 100Hz VBOX 3i is used by almost every automotive and tire manufacturer worldwide to measure brake performance to within 1.8cm.

BELOW: **RACELOGIC'S FLAGSHIP VBOX 3I FOR THE MEASUREMENT OF SPEED AND POSITION, INCLUDING BRAKE TESTING**

RIGHT: **USING A BRAKE TRIGGER TO START THE MEASUREMENT OF DISTANCE ALLOWS ASSESSMENT OF THE COMPLETE BRAKING PACKAGE. THE PURPLE SPIKE SHOWS THE MOMENT THE TRIGGER WAS ACTIVATED**



LOWER RIGHT: **TO JUDGE TIRE PERFORMANCE, A BRAKE TEST BETWEEN TWO DIFFERENT SPEEDS IS USED, WITH THE START SPEED CHOSEN SO THAT THE CAR HAS REACHED A STEADY STATE IN THE BRAKING PROCESS TO ELIMINATE RESPONSE TIME**



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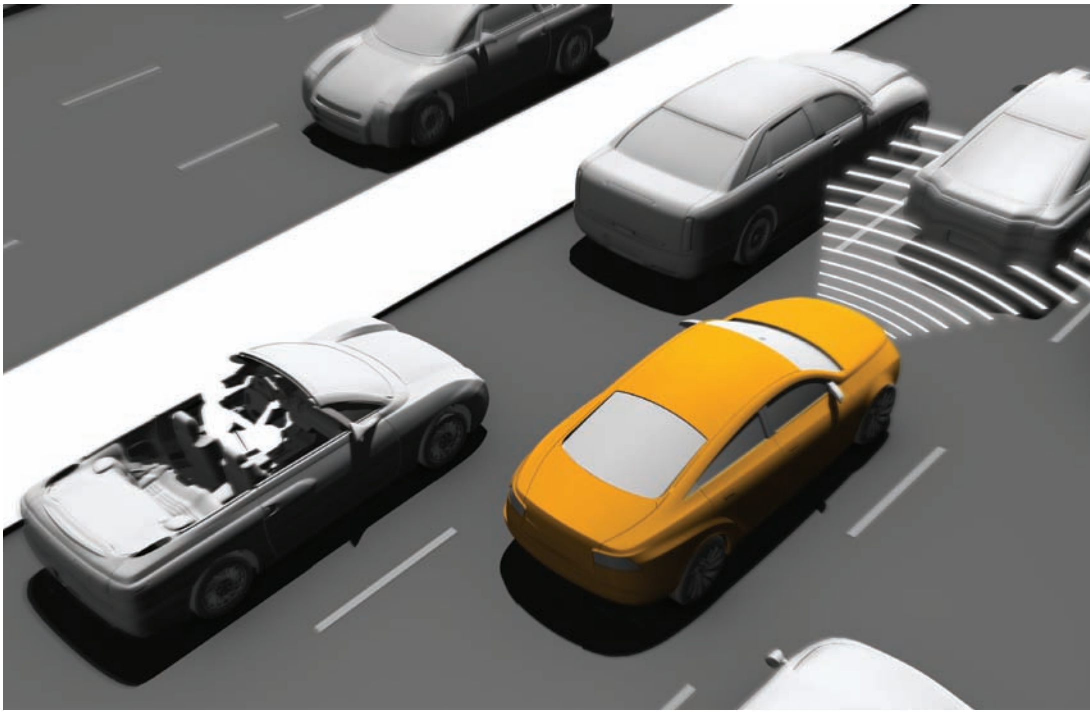
Quote ref VDI 014

Emergency city braking

Urban traffic requires considerable concentration on the part of road users. Other vehicles are in front, beside, and behind them at junctions, intersections, and traffic lights, alongside trucks, buses, motorcycles, cyclists, and pedestrians, all in close proximity. A brief moment of distraction can result in an expensive nose-to-tail collision.

Three-quarters of all accidents involving injuries occur in built-up areas at speeds of up to 30km/h. Accident research has shown that drivers delay applying the brakes in approximately 12% of car accidents and fail to brake at all in approximately 50% of cases.

This is where the emergency brake assist (EBA) intervenes. Emergency Brake Assist – City is an EBA system limited to speeds of under 30km/h, which can prevent nose-to-tail collisions at low speeds. Even if it fails to avoid the crash, it can greatly reduce the severity.



An optical sensor uses infrared laser beams to monitor the road space in front of the vehicle, up to a distance of about 10m. The sensor is mounted behind the windshield at the level of the rear-view mirror and rain sensor. From this position, the sensor's electronics measure the time that the emitted laser light needs until the reflection from an obstacle in front comes back to the sensor.

Based on this ultra-precise time measurement, the distance to an object in front can be calculated. Objects in front of the vehicle to which no reaction is desired (e.g. steam coming out of a manhole cover) are actively suppressed by clever algorithms, which have proved their effectiveness in more than one million kilometers of test drives.

If the distance to a vehicle in front diminishes so rapidly that a collision appears imminent, the brake system is immediately prepared for an oncoming brake maneuver by positioning the brake pads against the brake discs. If the driver then also applies the brakes, more braking power will be available considerably more quickly than if the system were not installed.

If the driver is inattentive and shows no sign of having recognized the danger of the looming collision, for example through executing an evasive maneuver or with a change of position of the accelerator or brake pedals, the EBA-City system will automatically apply the brakes at the very last moment. If the vehicle is moving faster than 20km/h, approximately 60% of the available braking power will be applied. This already results in a considerable speed reduction.

If the speed goes below 20km/h, full braking power is applied, which more or less leads to the vehicle coming to an immediate stop. In this way, speed differences of up to 25km/h between the two vehicles can be equalized, which will prevent an accident in most cases or, in any case, greatly reduce the severity of an impact.

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ABOVE: **EMERGENCY BRAKE ASSIST (EBA) FROM CONTINENTAL IS NOW AVAILABLE IN COMPACT CARS, TOO**

BELOW LEFT: **A MOMENTARY DISTRACTION CAN RESULT IN A COLLISION IN URBAN DRIVING**

Big wheels turning

JOHN HEIDER CONSIDERS THE HISTORY – AND FUTURE – OF WHEEL SIZING

> **"Nevermind the short sidewall height. The customer was happy to be riding in a vehicle and not on a horse"**

Despite causing countless hours of frustration for vehicle dynamics development engineers, the upsizing of wheels and tires across all vehicle segments appears to be here to stay. We should have seen this coming; it has been over 2,000 years in the making.

Go back in history as far as you like, but the most extreme incarnation of the large wheel/low-profile tire was also the first. This includes the all wheel/no tire installations on everything from Roman chariots, portable artillery, royal coaches, covered wagons or any other rolling vehicle pulled by a horse or pedaled by a human.

The development of the mass-production automobile in the early 1900s brought the widespread implementation of the pneumatic tire. The machine credited with bringing the automobile to the masses did us no favors; most early Model Ts rode on a 24in wheel/tire package. Using today's size convention, the tire would equate to roughly a 90/85-24 resulting in a very short 75mm sidewall height – good for ground clearance on non-existent country roads but bad for isolation. No matter, the customer was happy to be riding in a vehicle and not on a horse.

Development engineers working on ride comfort and NVH rejoiced during the 1920s with the introduction of the so-called balloon tire. For the next 50 years wheels got smaller, sidewalls got taller and widths increased, resulting in isolation levels rarely repeated since. But the yearning for the large wheel/low profile tire remained – how else to explain the "wide white" sidewall tires giving the appearance of more wheel and less tire?

Somewhere in the late 1970s or early 1980s, concept-car designers recognized this pent-up demand for larger diameter wheels with lower profile tires and the race was on. Initially the then-standard 15in wheel morphed slowly and rationally into 16s and then 17s by the mid-1990s, with tire aspect ratios dropping accordingly from 75 to 65 to 60 or lower. Designers began to rejoice, development engineers started to become worried – little did they know what was still to come.

The turn of the century brought about an unprecedented march from OEMs offering standard 17in wheel and tire packages to a "who's bigger?" competition to offer the largest possible optional wheel/tire package. Fueled by the general vehicle size enlargement in every class, designers and customers from the Hot Wheels generation and sales and marketing departments beaming over the additional revenue, the proliferation of OEM-offered 20in+ wheel and tire packages has been dramatic. Kudos to BMW for holding out as long as they have against the trend. But, alas, the smallest tire available on the 5 Series in the USA is now a 17in.

Is there a hope to reverse this trend? Will fuel economy standards drive us back to optional "high-performance" 15in wheels. I don't think so. OEMs usually find a way to satisfy customers in spite of government standards.

But development engineers need not despair. Tire companies have done a remarkable job improving the enveloping properties of low-profile tires to improve isolation and reduce transmissibility while simultaneously reducing air and structure-borne noise levels. In cooperation with our body engineering friends, systematically and accurately setting targets for suspension attachment point mobilities and acoustic transfer functions can provide a robust foundation for tuning, which can deliver extremely good levels of mid- and high-frequency ride comfort. Despite single wheel and tire assemblies weighing as much as 40kg, exceptional dynamics and NVH can be achieved with proper structural and chassis design and development.

So where do we go from here? Advanced tire projects suggest low-profile runflats, further advances in ultra low rolling resistance and possibly even the elimination of the pneumatic portion of the wheel/tire assembly. Hmmm....where have we see this before?

John Heider is from Cayman Dynamics LLC, providing vehicle dynamics expertise to the transportation industry: www.caymandynamics.com

NOWADAYS EVEN THE TINY ASTON MARTIN CYGNET CITY CAR COMES WITH 16in WHEELS AS STANDARD

ON THE WEB
Further comment from Heider at vehicledynamicsinternational.com

Is this a setup?

CARS WE DROVE RECENTLY THAT DIDN'T BEHAVE AS THEY SHOULD... OR DID THEY?

CASE 24: MERCEDES-BENZ CLS 250 CDI, BY JOHN MILES

Anyone who remembers a big Mercedes as a car for cruising along, divorced from the outside world, will be in for a surprise with the CLS 250.

Preconceptions might be confirmed when you see that it tips the scales at nearly two tons with a couple of occupants, and has only a 2.14-liter, 204bhp (at 4,200rpm) four-cylinder turbodiesel to haul it along.

But another glance at the spec and you see the astonishing mid-range torque figure of 500Nm at 1,600-1,800rpm. Now you begin to get the picture. At 0-60mph in 7.3 seconds it has all the thrust you really need, and 100mph comes up soon enough either using the seven-speed paddle shift or in fully auto mode – a quite remarkable power unit, and confirmation of the trend to small, high-boost diesels. Powertrain refinement seems virtually as good as any six, and the shift quality is good.

With 2.5 turns lock to lock, the steering ratio is fairly fast but well chosen for a big car, and with lots of assistance at low speed. This tapers off ideally above 30mph when the car seems to shrink around the driver, helped by the "clinching" function in the seat side bolsters. First touch of the brakes is reassuring too, as they kiss the speed away – unless really thrashed, when fade appears.

Twitch the steering and one is immediately conscious of the iron roll control, the firm lateral response on the optional 255/35-19 front and 285/30-19 rear Pirelli P Zero rubber, then the lack of braking pitch. Above 100mph the steering becomes heavy, especially five-up, when there is a less precise definition around center, and a certain vagueness in transient rear-axle response.

Moving on to more challenging surfaces, there are some issues. Mercedes retains strut front suspension, so with such an idealized damper velocity ratio it is a disappointment to find the front suspension "topping out" readily on long waves. On Norfolk's rippled and rough aggregate surfaces, front-axle shake and tremble dominates due, it seems, to a lack of unsprung mass damping. The longer you drive the more obvious it gets, suggesting damper fade. There is marked body kick and associated head toss (those stiff ARBs) on the UK's cambered and lumpy road surfaces. Front-axle secondary ride apart, the flat cornering stance, powerful brakes, and alert steering invite most un-gentlemanly progress along the country lanes.

The front-axle ride shake did rob the car of real classiness, but it was the road noise that caused most comment. In Germany it would be fine, but as we so often find, it is the UK's coarse aggregate and concrete road input that is so difficult to attenuate. In fact cabin noise rated no better than a Mondeo or Passat, something that the slightly taller, standard-fitment tires could have reduced, but hardly benefited the front-axle ride shake much.

In spite of these dynamic shortcomings, I enjoyed the CLS a great deal, especially that extraordinary powertrain.

SPECIFICATIONS
Mercedes-Benz CLS 250 CDI
Dimensions: 4,490mm (L) x 1,881mm (W) x 1,416mm (H)
Wheelbase: 2,874mm
Track width: 1,596mm (F), 1,624mm (R)
Weight: 1,785kg
Front suspension: MacPherson strut. ZF Sachs twin-tube, gas-pressure SDC dampers. Anvis damper bushing and strut mount
Rear suspension: Multilink setup. Monotube ZF Sachs SDC gas-pressure dampers
Steering: ZF Lenksysteme EPS. Turning circle 11.27m
Tires: optional 255/35 R19 (F), 285/30 R19 (R)

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