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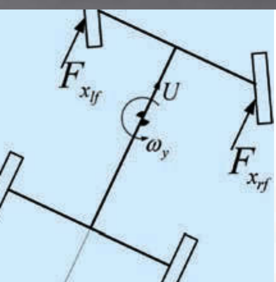
Kind of magic

Predictive suspension is here at last as Mercedes puts its road-scanning Magic Body Control into production



Technical papers

Research from Daimler and the University of California at Davis

Caterham 160

The Seven goes back to basics with a new rear axle

Korean focus

Inside Namyang and on the road in Kia's pro_cee'd GT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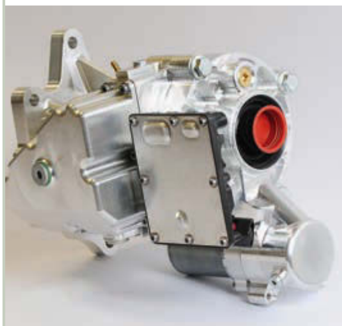

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A NOTE FROM THE EDITOR

Here at *VDI* we have our hobby horses. As a rule we like lightness, simplicity and good ride comfort; dislikes include short sidewalls, misplaced 'Sport' badges or buttons, and the dilution of the driving experience by multiple layers of electronic interference.

In this age of EPS and ADAS, it's becoming ever easier to empathize with King Canute. But we should give credit to electronic complexity where it's intelligently used. Take the Porsche 918 Spyder, for example – beautiful, powerful, expensive, fast, frugal even, but not light. Road-ready, it tips the scales at 1,675kg, from which the optional, lightweight 'Weissach' package deducts 41kg. Yet it's lapped the Nordschleife in 6 minutes 57 seconds.

With 875bhp and mountains of low-speed torque, traction and stability become more decisive than weight in the quest for outright lap speed. The 918's project manager, Frank Walliser, notes that the 918 is more stable than, say, the Carrera GT. "This was a new experience for us: the more stable it is, the faster it can be." The rear-steer system is key. Walliser explains that actuators added only 6kg to the car, but achieved the same lap time benefit as removing 100kg. Proof at last, perhaps, that less is not always more.

Not convinced? Then try the new 80bhp, 490kg, two-wheel-steer Caterham 160. The full story is on page 8.

Graham Heeps

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CONTRIBUTORS...AND THE WORST CAR THEY'VE EVER DRIVEN

MATT DAVIS
Alfa Romeo Brera Spider. The expectations for this Fiat-Saab-GM chassis were high, but it weighed about 500kg too much, had horrendous suspension behavior, and the high-speed braking was so dangerous that I ended up driving it timidly enough to avoid having to use that pedal much!

JOHN HEIDER
Any number of disastrous early prototypes with no sound package, no body sealing, barely running powertrains and 'best-guess' suspension settings! Success was making it back to the garage without having to call a tow truck. Far worse than any production vehicle on the road in the last 50 years.

BRIAN LABAN
It was a British-built, US-style 'quarter-midget' on a very low-rent, 1970s shale oval. It had far too much V8 power in a chassis that was beyond crude, with a wheelbase about the same as my shoe size and the gearstick between my legs. The consequences of the probable contact with steel-rope barriers gave considerable pause for thought!

TONY LEWIN
The worst cars are those built by major corporations that should have known much better. Like Toyota with the awful Carina E, its first UK-made car. This was noisy, boomy, bouncy and had a low-rent interior with shiny dashboard and even shinier seats, trimmed in what appeared to be industrial-grade nylon!


MAGICCARPICS.CO.UK

KEITH READ
Without doubt, the AMC Pacer. Too many revolutionary design features were simply so far ahead of their time that they were perceived as flaws. But my main reason for citing it is that it weighed twice as much as comparable cars and handled like a pig. Such was the criticism from UK media that imports stopped almost as soon as they'd started...

Touch of magic

MERCEDES' NEW MAGIC BODY CONTROL USES CAMERAS TO READ THE ROAD SURFACE AND ADJUST THE SUSPENSION ACCORDINGLY. **TONY LEWIN** REPORTS

Chassis engineers tasked with ensuring supreme ride comfort in a luxury car labor long and hard to hone their suspension, damping and bushing settings to achieve near perfect wheel control and road surface isolation. Each must also be struck by the thought that however clever the basic suspension system is, it would be able to perform even more effectively if it knew what road conditions it was about to encounter and had the chance to prepare itself.

That dream of a live preview of the road surface ahead was brought closer to reality in 2007 with Mercedes-Benz's F700 concept, which proposed just such a system. And now, true to its tradition of bringing groundbreaking innovations to market, Mercedes is offering anticipatory body control for real on its new-generation W222 S-Class.

Dubbed Magic Body Control (MBC), the new system uses a stereo camera to scan the road surface up to 15m ahead, identifying bumps and dips and commanding the suspension's hydraulics to raise or lower each wheel to suit the type of obstacle before the car reaches it.

What is more, as S-Class chief engineer Dr Hermann Storp explains, the MBC system on the new car is almost precisely as envisaged on the F700 concept: "It's basically the same as the system we showed in 2007, but at that time we needed a lot of equipment and computers in the car," he admits. "What you see now is the version we can offer on the market to every customer."

The claims Storp and his team make for MBC are impressive. "With bumps of up to 18cm (7in) you don't feel anything," he says with relaxed confidence. "When they're bigger than that, you do feel something, but it's much less than you would feel without MBC."

Traffic-calming speed bumps, he says, are especially well handled, citing the example of a TV crew that drove at 50km/h over just such a bump with a full glass of water on the console. Not one drop was spilled.

Needless to say, the technology behind this claimed step-change in comfort is far from simple. Signals from the screen-mounted stereo camera (made by Continental) are continually analyzed to identify upcoming road-surface features. Juggling a matrix of dynamic parameters, the central processor then decides whether, when and how much to intervene in the suspension. Each Sachs-supplied suspension strut has an extra hydraulic plunger and available pressure of 200 bar to either raise the wheel (for a bump) or lower it (for a pothole). All four wheels are adjusted independently. At the same time, damping rates are also adjusted to match each upcoming road surface feature.

Storp is reluctant to quote reaction times for the system but says it operates at up to 130km/h, equivalent to 36m/sec. Given the 15m obstacle identification horizon, this would point to a reaction time of under half a second. Significantly, MBC is only active when the vehicle is in its Comfort mode; in Sport, when arguably the need for bump mitigation is greater, the system is switched off. The vehicle's stability always takes precedence over comfort systems such as MBC. "If someone approaches a curve at high speed, the effect of the MBC system is decreased," he says. "It's a comfort system, not something to support racing."

SPECIFICATIONS

Mercedes-Benz S-Class

Dimensions: 5,246mm (L) x 1,899mm (W, without mirrors) x 1,494mm (H). Wheelbase: 3,165mm. Track width: 1,624mm (F), 1,637mm (R)

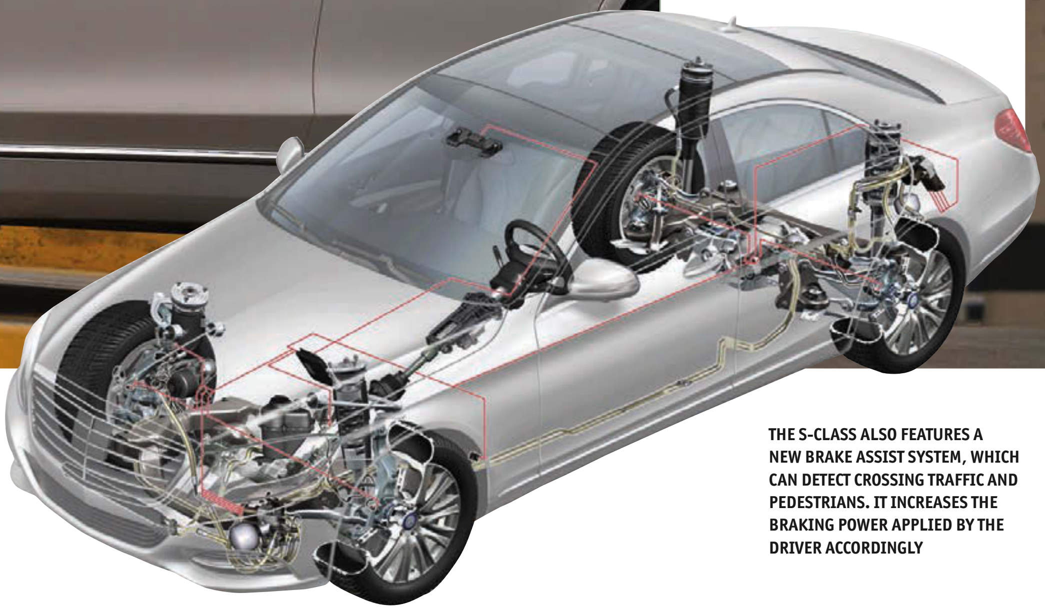
Dry weight (S350 CDI): 1,955kg

Suspension geometry: Camber -0.5° (F), -1.9° (R); toe 0.2° (F), 0.5° (R); castor 9.5°

Steering: TKPS (2WD), ZF (4WD). S350 ratio 15.5:1, turning circle 11.9m

Brake suppliers: Daimler, Brembo, TRW and Jurid. Bosch ABS/ESC

Performance (S350): 155mph (250km/h) electronically limited top speed. Acceleration 0-62mph (0-100km/h) 6.8 seconds



THE S-CLASS ALSO FEATURES A NEW BRAKE ASSIST SYSTEM, WHICH CAN DETECT CROSSING TRAFFIC AND PEDESTRIANS. IT INCREASES THE BRAKING POWER APPLIED BY THE DRIVER ACCORDINGLY

The sophistication of the system is such that it can distinguish individual three-dimensional road features such as ridges, ruts and holes, where the suspension needs to react, from features that are simply painted onto the road. Yet, as Storp explains, the development process has been far from straightforward and sometimes seemingly innocuous road features such as pedestrian crossings caused confusion:

"We realized the system wasn't working when approaching the zebra stripes: it wasn't sure if it was a bump or not," he reveals. "But within the software system we know what these zebra stripes look like, so now when the camera shows the stripes the system knows that no reaction is necessary. It's part of the intelligence of the system to recognize features and know whether or not to react."

So how long have engineers at Mercedes been working on this type of system? Says Storp, "In the pre-development area it is our task to come up with technologies that might be worth launching. Seven years ago we realized that we might have an opportunity with this, and we started to develop it for series applications about five years ago."

Apparently the idea was first explored some 20 years ago but the available cameras and software were not up to the task. Drawing a comparison with night-vision systems, which also took some five years to bring to series production, Storp underlines the importance of being sure the basic concept is worth pursuing.

Part of that decision process is to distinguish between major 'red flag' issues (such as the limited cameras of 20 years ago) and minor difficulties that can be overcome. The latter category includes the need to find a particular type of distortion-free windshield glass for the camera to look through.

Storp concedes that the MBC system still has some limitations. It cannot cope with sharp edges or rumble strips, and it is less effective in the dark and when the road surface is wet – it would not be able to recognize a pothole filled with rain water, for example. "We're at the limit of what a 3D camera can do," he says, "but I hope that in three years we will have made the next step."

VDI SAYS

The complication involved in making Magic Body Control production-ready marks it out as a major innovation, for which Mercedes and its suppliers are to be commended. The potential side-effects of the system (chauffeurs launching over speed humps while taking a short cut through residential areas?) are yet to be seen...

Final fling?

AS **JOSHUA DOWLING** REPORTS, A NEW TIRE CHOICE IS KEY TO THE LATEST – AND POSSIBLY LAST – IN A LINE OF FIRE-BREATHING AUSSIE V8 SEDANS: HSV'S GTS

A supercharged, 6.2-liter 'LSA' V8 (with 577bhp of power and 740Nm of torque) is enough to propel the 1,900kg Holden Special Vehicles (HSV) 'Gen-F' GTS to 62mph (100km/h) in 4.4 seconds. With the future of Australian car making under a cloud due to high labor costs, a strong Australian dollar, and limited export potential, the HSV GTS could well become a fitting exclamation point for the local industry.

Developing Holden's performance car range since 1988 has been Holden Special Vehicles, a separate company owned by the late Tom Walkinshaw and now overseen by his son Ryan.

The Gen-F GTS is the highlight of the HSV range, and the most complicated, exhaustive and expensive engineering program in the company's history.

HSV says the sheer magnitude of the HSV GTS program – and the high level of performance – prompted an evaluation of the company's tire requirements. Japanese tire maker Bridgestone had been the primary supplier for most of HSV's 25-year history, but HSV opened its doors to other suppliers on this occasion.

"When we started the search, we were simply after the best performance tire we could find," says HSV chief engineer Graeme Dusting. "After evaluating a broad range of tires from all around the world, we shortlisted three suppliers – Bridgestone, Yokohama and Continental. After this evaluation, one tire stood out from the rest – the ContiSportContact 5P, which offered exceptional performance in both dry and wet-weather conditions."

ABOVE: **THE GTS'S BWI TWIN-WIRE, DUAL-COIL (TWDC) MAGNERIDE UNITS ADJUST THEIR DAMPING 1,000 TIMES PER SECOND. THE CAR IS ALSO SOLD IN THE UK AS THE VAUXHALL VXR8 GTS**

HSV conducted countless tire test days and Bridgestone tried hard to not lose the HSV contract, including flying engineers out from Japan with newly developed tires. But in the end the data showed the Continental tires had the edge in HSV's key criteria.

The Continental 5P tire was originally developed for the Mercedes-Benz E63 AMG in a 19in configuration but Continental wanted to expand its fitments.

"Although outstanding from the outset, it took 12 iterations of both the front and rear Continental tires before we signed off on the 5P," says Dusting. "Using our Holden Racing Team V8 Supercar driver, Garth Tander, as our test driver, the Conti 5P tires consistently delivered a 1-second laptime advantage over the competitive makes (up to 2 seconds in the wet) around the Winton Raceway (typically a 1-minute lap). Steering response, tire stability, handling balance, ride quality, road grip and braking distance were key evaluation criteria."

The tires were tested on HSV's 20in SV Performance lightweight 10-spoke forged wheel (available on the latest GTS as an option). The tire sizes (on 20in x 8.5J front rims and 20in x 9.5J rear rims) grew to 255/35 R20 (versus 245/35 R20 on the predecessor car) and 275/35 R20 (versus 275/30 R20) respectively.

All testing was done in-house, at Winton and Broadford racetracks, Holden's Proving Ground, and suburban and country driving.

"We aimed for the best possible balance between driver feel, comfort and car balance," says Dusting. "We also needed to ensure optimum integration with the ESC work being done with Bosch."

HSV also upgraded the GTS to BWI's third-generation MagneRide dampers, paired with Monroe springs. HSV would not disclose spring rate changes and damper settings, but on the road the suspension, combined with the softer sidewalls in the Continental tires, delivers an impressively smooth ride despite rolling on 20in rims.

"Ride comfort was very important but not at the expense of grip," says Dusting. "The driver can adjust the ride settings to suit personal preference or driving conditions."

VDI SAYS

Given its awesome power, it's fitting that the HSV GTS 'Gen-F' has the best ride and handling combination of any HSV to date. BMW and Mercedes engineers should try one to see that it *is* possible to remove harsh impacts on bumps, even when the car is running on 20in rims.

NEWS-IN-BRIEF

From early 2014, dSPACE will offer simulation models for pneumatic-brake and air-suspension systems. The ASM Pneumatics model library will become part of the dSPACE Automotive Simulation Models (ASM) product family and is said to be ideal for developing and testing electronic brake systems, air suspension ECUs and level-control ECUs.

Derived from its racing products, AP Racing has created a new range of Radi-CAL brake calipers for high-performance road-car use. Available as six- and four-pot front calipers, as well as a four-pot rear caliper, the forged, non-symmetrical calipers are claimed to provide a significant reduction in mass and improved caliper efficiency when resisting the torque generated by braking.

TRW Automotive is supplying Ferrari with its electrically powered hydraulic steering (EPHS) technology for the LaFerrari. The EPHS system offers fuel savings of up to 0.3 l/100km and a reduction of carbon dioxide emissions of approximately 7g/km when compared with traditional hydraulic power steering systems.

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Sub-system testing photo courtesy of IMA-Dresden

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Roots maneuver

A SMALLER ENGINE, A NEW REAR AXLE AND NARROW TIRES TAKE THE ENTRY-LEVEL CATERHAM SEVEN 160 BACK TO ITS LIGHTWEIGHT ROOTS. NO STRANGER TO TUNING A SEVEN, **JOHN MILES** REPORTS

NEWS-IN-BRIEF

Companies from the off-highway and special vehicle industries have joined forces to develop a cost-efficient steer-by-wire system compliant with EN ISO 13849. OEMs, such as CNH, Crown, Dynapac and Liebherr, together with suppliers Dana, Spicer Off Highway, Eaton Corporation, HYDAC, Lord, MTS Sensor Technologie, Danfoss Power Solutions and TTControl are part of the collaboration.

Continental has developed a new motorcycle ABS that is approximately 50% smaller and lighter than previous systems. The MK 100 MAB, two-channel ABS is suitable for all motorcycle types and will initially go into series production in Europe in 2015. The technology offers enhanced features as well as increased sturdiness, and can be more easily adapted to different motorcycle types.

The new Winter Sottozero 3 from Pirelli is a UHP winter tire developed for premium cars with medium to large engines. It was tested through extreme winter conditions in Italy, Austria, Sweden, Finland and New Zealand and features 3D sipes. An innovative compound improves the mechanical, thermal and dynamic properties of the rubber while a more rounded shoulder helps disperse more water.

The question for Hingham, UK-based Caterham Technology and Innovation (CTI) was how to re-engineer the entry-level, but time-expired, Rover K-Series-powered Caterham Seven Classic, with a light, cost-effective, emissions-legal and available rear-wheel-drive powertrain.

It was the Caterham agent for Japan who suggested looking at the 660cc, 60bhp three-cylinder turbo engine and five-speed rear-wheel-drive powertrain from the Suzuki Jimny/Every pickup/van platforms.

Already Euro 5 emissions legal (with Euro 6 soon available), it needed only turbo recalibration, via Caterham-developed software, to generate a turbine-smooth 79bhp at 7,000rpm and 107Nm torque at 3,400rpm, against the 103bhp at 6,000rpm and 128Nm at 5,000rpm for the Rover K-Series unit. Less power and torque perhaps, but at 490kg curb weight, the resulting Caterham 160 (165 for export markets) would be at least 35kg lighter, a useful proportion of which comes from significantly narrower 14in x 4.5J wheels, shod with 155/65-14 Avon ZT5 tires.

The tires help to fulfill the objective for safe and accessible rear-axle slide-ability at low-ish speeds and there is a further advantage regarding steering kickback, thanks to the 18mm reduction in ground offset. The resulting 50mm narrower (1,220mm) front track and 1,470mm overall width also means the car can be sold in Japan. Despite the reduction in outright power, the lightweight 160 gets to 60mph in a claimed 6.5 seconds, compared with the 6.8 seconds quoted for the old K-Series car, with both achieving about 100mph all out.

Sole modifications to the MIG-welded R400 tubeframe are those involved in packaging the new rear axle and suspension linkage. Ultimately, Caterham's Dartford production facility conceded that the kinematically and compliantly unsound location of the old BL Ital-derived rear axle by a lower 'A'-bracket and two upper trailing links needed to be replaced with a five-link system. This consists of the usual two pairs of equal length parallel trailing arms and a Panhard rod for sideways location.

Chassis engineer Hugh Wright's new design cleverly utilizes the existing forward chassis mounting points, with new bracketry required only on the axle itself for mounting the equal length trailing arms, which virtually eliminate differential rotation. Realignment of the two lower diagonal chassis tubes – thus creating true triangles – reduces frame stress by 65%, and in turn stiffens the whole rear-end structure

THE '160' NAME COMES FROM THE CATERHAM'S BHP/TON FIGURE. CAD IMAGE SHOWS C160 ROLLING CHASSIS WITH REVISED REAR AXLE

laterally, enough to permit cornering stresses to be absorbed by a Panhard rod. This has all been achieved for a weight gain of just 2.7kg.

The static rear roll center height has climbed from a nominal 117mm to no less than 186mm, which might have been worrying, except that the roll center now falls in roll. The previous 'A'-bracket suspension guaranteed no lateral axle displacement with vertical movement (five-link: 4.5mm), but translated a hefty 9.6mm sideways at 4° roll, which tended to wreck the overstressed lateral location bush, the axle itself, and differential bracket, which was also vulnerable to grounding on big bumps. Relevant figures are now 5.8mm in bump and 1.3mm in rebound. Anti-squat and anti-lift values were 143% and 22% respectively, but are now a much more appropriate 29% and 12% for a car with a 450mm CoG height. Angularity changes are now comfortably accepted by the suspension bushes.

The 160's front suspension is common to the R400 and employs a 16mm diameter anti-roll bar – the stiffest available.

Mid-laden suspension frequencies of about 1.3Hz front and 1.8Hz rear are approximately those of the R400, but are achieved with only 20N/mm front and 19N/mm rear springs due to the absence of mass. In the mid-laden, 75kg driver-only condition, the rear tires support 55% of the weight, so no surprise that with equal-sized tires all round, development engineer Myles Lubbock and program manager Dave Minter report tuning for steady-state slight understeer, but easily accessible and very progressive oversteer aka "accessible fun", dry or wet.

Like the R400, the 160 uses Bilstein E36 monotube dampers, but these are now fitted with the standard, volume-production, double-bleed piston, whose extremely digressive rebound characteristics (which give a tendency to jerky rebound over control) have had to be tamed, as on the Lotus Elise, by a 'split' rebound shim pack to get a smoother ride feel at low damping velocities (body frequencies). Suspension bushes are of the simple cotton-reel type from the Caterham parts bin, while bump stops are supplied by Bilstein in a similar off-the-shelf manner.

VDI SAYS

The Caterham Seven 160 is a highly attractive, lightweight package that is likely to significantly increase sales in all markets, especially Asia and Europe. At £14,999 for the kit and £17,995 built, it undercuts the previous Classic by at least £2,000. Success is surely guaranteed.

NEWS-IN-BRIEF

In order to counter the influence of a longer rear overhang and potential cycle carrier installation, Honda has fitted adaptive damping to the rear axle of its Civic Tourer. The system uses ZF Sachs Twintube CDCi dampers, which are combined with a Honda-developed ECU complete with an internal *g*-sensor. The ECU additionally takes readings from the steering, throttle and brake sensors every 10ms via existing CAN signals. By not adding any other sensors or wiring, Honda claims that its system offers around 75% of the performance of a four-corner setup, but with no major impact on the vehicle's weight, electrical consumption and overall cost.

The Porsche 918 Spyder's suspension tuning was informed by the company's experience with the RS Spyder LMP2 program (from which the road car's V8 engine is also derived). "We learned that for traction, the softer chassis is definitely better," explains the 918's overall project manager, Frank Walliser. "In the beginning, the RS Spyder had a really stiff suspension, but the experience gained was that as it got softer, it became faster." The 918 has PASM damping but the springs are conventional; rates are similar to the 911 GT3.

Forge ahead

KEITH READ FINDS OUT FROM ONE OF MVO'S MDs, DR NIELS VIEWEG, HOW A RECENT INVESTMENT IN A WARM-FORGING CELL WILL HELP MEET DEMAND FOR VR RACKS

NIELS VIEWEG AND TWO VIEWS OF THE NEW WARM-FORGED STEERING RACKS (ABOVE, BELOW)

The first fruits of a US$6.5m investment in a warm-forging cell by MVO, one of the world's leading steering rack manufacturers, are about to appear on vehicles being developed on a common platform by two of Europe's major auto makers. Use of MVO's variable-ratio (VR) racks by the manufacturers pays tribute to a shrewd business move by the company's joint-MD, Dr Niels Vieweg. He bought the Sydney-based Bishop group of companies, which not only invented VR rack-and-pinion technology in the 1980s, but later also developed the patented warm-forging process.

MVO has a unique position in offering the technology on the open market, so further similar investments are likely. The demand for VR steering – predominantly found in premium-sector vehicles today – is predicted to increase within the mass-market. "Our first warm-forging cell investment was huge for a relatively small company," says Vieweg, "but it's great for the future."

The new process gives MVO – based in Schwäbisch Gmünd, 30 miles east of Stuttgart – an increase in annual output of 1.2 million units, which is already spoken for. "We will look at a second investment, to be completed by the end of 2015/beginning 2016, that will double output capacity," he adds. "And, if necessary, we can make a third investment in the USA at our plant in Indianapolis. But it will be market-dependent, as demand for VR steering is not as high in the USA as it is in Europe."

While 93% of the total market still uses constant-ratio steering racks, the swing to electric steering systems will influence demand for VR racks. MVO has developed its new low-cost range of VR steering racks to be ideally suited to the cost-effective CEPS (column electric-driven steering) and PEPS (pinion-drive electric power-steering) systems favored by many manufacturers. The racks use less raw material and have fewer process steps than alternative steering-rack solutions, meaning reduced weight and lower costs.

"With warm-forging we can take a bar, forge it, and have the teeth finished without doing any machining," explains Vieweg. "With a conventional rack you grind or broach teeth away. So you end up with a shaft that is weaker where the teeth are, which is where the maximum loading is… The classical steering rack is an inherently unbalanced product in that you machine material away where it has the highest stresses.

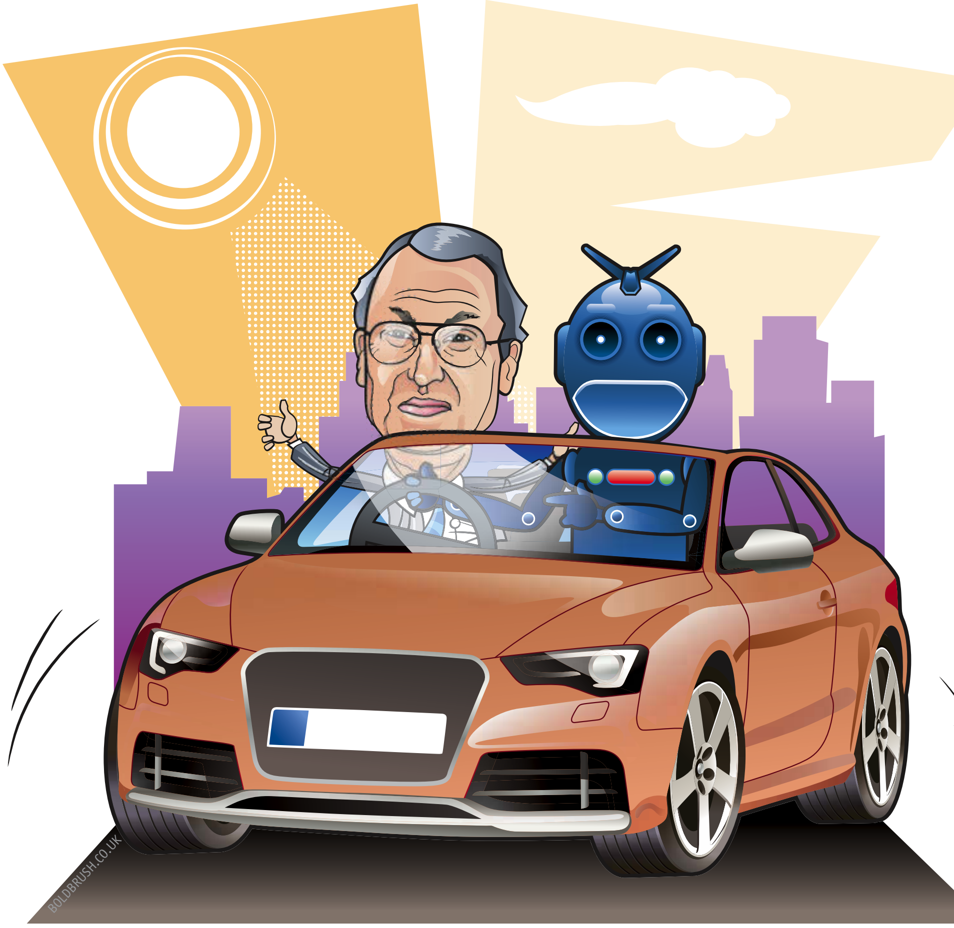
"What we do is start with a smaller diameter bar, which is strong enough in the shaft to take the loads, and then forge it out with wider teeth. In the shaft we might have a 22mm rack, but in the teeth areas we might have a 26mm rack. Essentially, we don't waste any material. We don't put any more material into the product than necessary and we don't have to machine it away. What we end up with is a lighter product for the same strength which, of course, helps us to optimize the cost to the customer. This is particularly relevant with CEPS and PEPS systems – the mass market – where cost pressure is much higher."

A typical weight-saving achieved by the warm-forging process alone is a 4kg rack reduced to 3kg. Other advantages include a reduction in the size, weight and cost of the EPS motor drive and the elimination of compromise. "With constant-ratio steering the challenge is always to find the ratio, and that's driven by a number of things," says Vieweg. "But with VR steering you can separate these things. Because it is bespoke, it allows you to tailor the steering to a particular vehicle. This is important because vehicle dynamics is more of a discussion today than it was 10 years ago, partly because we now have all these driver-assistance systems, such as park-assist."

On the job

Robot wars

AS DRIVING BECOMES MORE AUTOMATED, A CONCERNED **JOHN MILES** TAKES COVER



It seems that software engineers now dominate even in the world of vehicle dynamics. The progression is quite logical – from ABS and stability control, via brake-force distribution and automatic proximity braking, and then to EPS, which allows the stability-enhancing micromanagement of steering tie-rod loads, a feature VW was early to exploit. Lane-wander warning systems are with us and, if ever legalized, satellite-monitored speed and journey tracking – beware you unfaithful husbands parked in the woods! But just over the horizon is coming something else altogether. I refer to what Toyota terms 'automatic pedestrian collision avoidance'. It's simply marketing speak for steering control intervention in an emergency – the one control function that should forever be left to the driver.

It's annoying having the hidden hand of a proximity braking system intervening unwantedly but it's hard to argue against automatic braking in principle, especially when coupled with a collision-risk warning light, followed by an audible alarm warning the driver to take avoiding action as the likelihood of an impact increases, at which point pre-collision braking force is triggered. This I can see is useful, especially in fog, in that it is better to be hit from behind (unless by a truck) than to plow head-on into something solid.

Dealing with vaguely predictable trajectories is one thing, but the ability to detect a pedestrian's or animal's next move is surely another. Yet that's what several manufacturers are working on: systems that can detect that if a collision cannot be avoided by braking alone, steering intervention will come to the rescue – so called 'pedestrian avoidance automatic steering'.

I see trouble ahead because human beings – never mind other members of the animal kingdom – are so unpredictable in their behavior. How can software detect whether a pedestrian is suddenly going to step off a crossing and then step back? Run to the left or run to the right? And how can radar, lidar or cameras differentiate between a big traffic cone and an animal or child? Who decides what field of vision to cover, or the trigger point for the systems? The bigger the field of vision, surely the more likely there will be sudden unnecessary steering intervention.

Pre-collision braking systems and seatbelt-tightening may have achieved a step-change in preventative safety, but steering intervention even up to a moderate (but over-comeable) 15Nm torque is a step too far for me. I'd hate to have some element of steering control in the background like a second driver, waiting there to turn the wheel in the opposite direction from me, or even in the same direction, thus dramatically changing the apparent aligning torque and directing the car straight into a wall, barrier or, worst of all, a tree. There are certain to be software glitches, as there have been with fly-by-wire aircraft.

> "Even a 1-liter Fiesta does well over 100mph – faster than many light aircraft – yet no car-control or limit-handling training is required"

Recent UK statistics point out that 20% of serious accidents are caused by 5% of young drivers. This suggests that as well as a general lack of practical skill and understanding of where handling, braking and adhesion limits lie, not enough attention is been paid to anticipation and observation in the driver training process. A driver's license holder is in charge of a lethal machine. Even the very likeable, base-model, 1-liter Fiesta does well over 100mph – faster than the top speed of many light aircraft – yet no car-control or limit-handling training is required. Observation and anticipation need to be stressed – looking ahead, and not so much gazing fixedly at the car in front.

Software has now successfully decreased limit braking, and improved handling and stability, and for that matter has been shown able to eliminate or minimize straight-ahead collisions. It will soon be an essential part of Euro NCAP 5-star ratings, but once these systems intervene in the steering function, even up to a moderate handwheel torque, I can't buy into the concept. As in the ABS case, where some drivers placed too much reliance on its capabilities, I believe that pedestrian avoidance automatic steering is sure to give a false sense of security, leading to over-confidence and perhaps an even bigger crash. And I dread to think of all the long-term durability issues there are likely to be with these systems, which seem to be an effective way of increasing the car scrappage rate.

As I write this I can imagine the courtroom dialog. Judge: "So why did you hit the pedestrian?" Motorist: "I don't know what happened your honor, the car suddenly took on a life of its own!"

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MATT DAVIS SAMPLES INFINITI'S BY-WIRE STEERING SYSTEM. FLOP, OR THE FUTURE?

All right cowboys and girls, let's brace ourselves for more steering pioneering on the wild frontier! I could actually just yammer on about electromechanical steering, as is my wont, but I'll be honest (at least for a moment) and admit that the software and ECU-interfacing for premium cars' steering is improving by leaps and bounds seemingly by the month. The technology marches on much faster than even I could have wanted (see *VDI*, June 2013) and I am now feeling at one with the electro-steer trend through almost all curves and in any caliber of car. It's all still numb, but well done.

I recently drove the incredibly interesting Infiniti Q50 smaller sedan, which comes in rear-wheel-drive and all-wheel-drive versions. There is also a hybrid trim using a 3.5-liter V6 gas engine with help from a 150kg lithium-ion battery assembly mounted directly behind the rear seat backs and thus quite high up in the structure. The all-new modular chassis architecture, while sharing an almost identical wheelbase to the outgoing architecture of the G37 sport sedan, gives 50mm-wider tracks in the normal setup. Other new tech includes active lane control (ALC), which hints heavily at an autonomous-driving future, and most notably direct adaptive steering (DAS). This latter item is the world's first application, for public purchase and use, of a true steer-by-wire system that depends totally on the car's electronics.

As I looked around at my fellow testers sampling the DAS-equipped cars, the whining was unmistakable. It has in fact led Infiniti to order all its technical people to not reveal the current supplier of the technology design, though my bet is on Jatco in Japan. The sheer fact that you can select via the onboard computer interface whether to leave DAS engaged or in the background does speak volumes to me about the current state of steer-by-wire.

But regardless of the volume of the whining from various corners of the globe, steer-by-wire is the future for nearly everyone sooner or later. It helps packaging immensely as it can do away with any steering clutch at all between the column and the rack. It therefore lowers weight, and going full-wire opens up a whole new realm of steering calibration and (eventual) precision. At the moment, though, it is simply a very weird feeling.

I drove all versions of the Q50 and I could swear that the rear-wheel-drive chassis dealt much better with the combined standard DAS and ALC of the more costly hybrid version than did the all-wheel-drive chassis with its central clutch pack by the aforementioned Jatco. Aside from any debate on the steering stratagem, it is pretty brain-filling just how much fiddling about one can now do with Infiniti's dynamics on what is supposed to be its simplest car for the premium masses.

> "It is pretty brain-filling just how much fiddling about one can do with the dynamics on what is supposed to be Infiniti's simplest car"

Between the all-wheel-drive unit, the DAS, the ALC and the adaptive chassis/drivetrain toggle-switch to choose between five setups (ranging from Standard to Personal), I cannot fault Nissan-Infiniti for bringing this thing way up-to-date to compete more heartily with the dynamics choices of a BMW 3 Series or Audi A4. That said, I shall not whine, but simply state that this sort of feel at the steering wheel has a couple more generations to go before I stop leaving both the DAS and ALC switched off while driving my premium AWD hybrid.

Enlightenment takes time, sometimes. In fact, it took me a few laps of the created obstacle course to get used to slaloming or taking evasive maneuvers at speed, with all the tech switched on and the onboard setup in Sport. I am not exaggerating when I say it is absolutely kart-like in its reactions, so the company's claim of having the world's most responsive steering system is by no means a fib. It's simply a bit too responsive in this first iteration.

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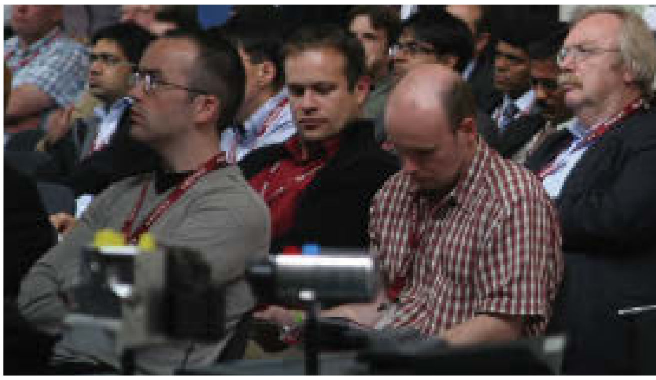

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KINESTHETIC PERCEPTION OF THE HANDLING BEHAVIOR OF DIGITAL PROTOTYPES BASED ON MULTIBODY SIMULATION IN CLOSED-LOOP TESTING. BY **FABIAN REGH, CHRISTOPH BÖHM, LUC DIEBOLD** AND **UDO WEIST** FROM DAIMLER, SINDELFINGEN

Today, physical vehicle modeling that allows reliable predictions is achieved by way of complex multibody simulation (MBS) models. To enhance the quality of prediction, flexible components, controllers and complex component models are integrated in a cosimulation. For this it's obligatory to have empirical or physical tire models that are precisely known in the simulated operating points.

The driving dynamics models that can be used in real time are usually parametric models or multibody simulation models with reduced complexity. Real-time capable models are predominantly parameterized by way of measurements conducted on real prototypes and their components.

To assess the driving dynamics properties of passenger cars and trucks, and for live trials of driver assistance systems, Daimler employs a dynamic driving simulator with hexapods and an additional linear drive with 12m of space for movement. This is one of the most powerful devices of its kind anywhere in the world.

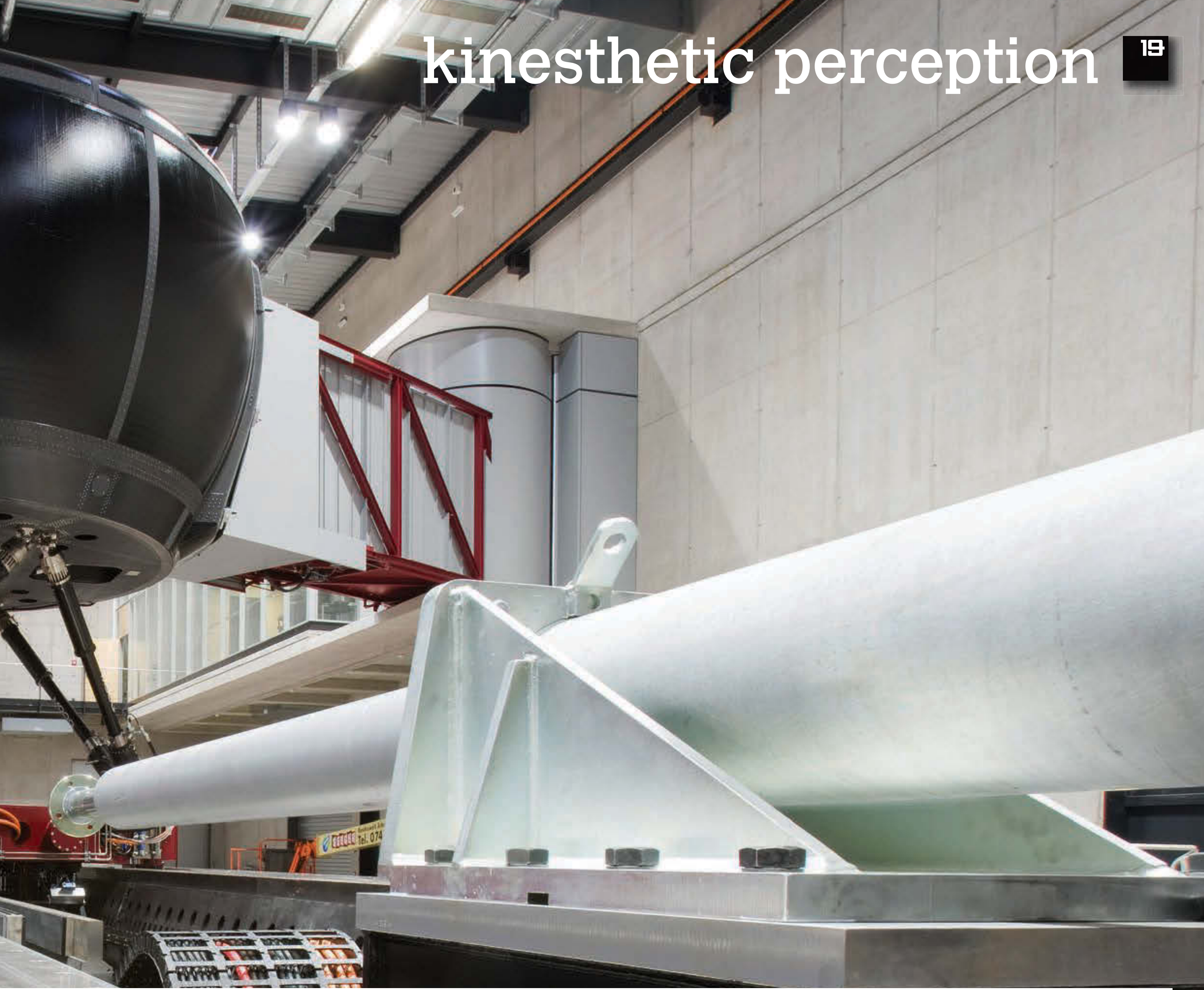
The objective is now to perform kinesthetic simulation of the driving properties of a vehicle modeled completely using MBS in closed-loop maneuvers. Besides the provision of a suitable virtual test environment for load cases, and the transposition of model-based prototypes to parametric models, the automation of parameterization and the validation of the methods used are the primary challenges of the project presented.

An open-source program based on MATLAB Simulink is used for the real-time simulation program. This allows models to be individually adapted to vehicle specifications. Validation testing by way of driving-dynamics protocols and driving-dynamics calculations confirms the high quality of prediction achieved with the MBS-parameterized model.

Motivation

The current development cycle for motor vehicles is characterized by the definition of model series and by the derivation of variants. One benefit of this is the reduction in the number of physical prototypes that can be achieved by carrying over the findings from basic types. With today's diversity of derivatives, the description of all possible variants at all development phases and for all development activities would be excessively costly in terms of resources. Some of the objectives of the investigation are achieved exclusively by simulating many of the possible vehicle variants.

Reliable predictions are already possible in the field of overall chassis simulation, for example with respect to elastokinematics. MBS programs, some of which are rather complex, are used as investigative tools. The method of MBS can be modeled for specific load cases. This creates an efficient calculation for straightforward maneuvers, for example when stationary. For the description of complex scenarios, a maximum degree of prediction reliability is guaranteed by the



incorporation of component models, which are in part rather complex.

In contrast to MBS models, parametric simulation tools do not make use of component-orientated data gathering. The freedom of the models is reduced such that the elastokinematics are described on the basis of characteristic curves. This reduces the calculation time so much, even compared with simple MBS models, that it can be performed in real time on conventional computers.

Data measured on test benches or in physical driving tests is used as input variables for parametric systems. However, because the data is already available in MBS, parameterization is now performed automatically from the simulation. In addition to real-time simulations of driving dynamics, the kinesthetic simulation of digital prototypes is now also possible. These can be modified according to the component concerned in the MBS and subjectively assessed in the simulator.

The state of the art

Simulation methods in chassis development range from ride and handling predictions via the optimization of NVH behavior to other calculations, e.g. to validate robustness. Chassis simulations calculate passively as well as by including regulators. Software-in-the-loop (SIL) methods include the description of controller algorithms and their interactions with the vehicle model. However, within the vehicle there are controllers integrated into the control units and these also include algorithms for guaranteeing and monitoring a high degree of functional reliability.

The validation of the control units and their functions is increasingly performed on hardware-in-the-loop (HIL) platforms. Here, chassis/driving dynamics simulations work in cosimulation with the physically present control units. In the case of a vehicle-in-the-loop (VIL) test bench, the vehicle is also physically described. Here, the calculation is used to monitor, verify the plausibility and if necessary generate and overlay interference signals for the stimulation.

Simulation methods are systematically used to predict driving dynamics and ride comfort. Here, a distinction can be made between MBS models and parametric models.

MBS models include component-orientated data gathering with the assembly concerned being configured according to the specific investigation objective. Investigations of the vehicle behavior in the low-frequency range, for example the simulation of stationary driving dynamic maneuvers, can usually be performed with purely rigid-body models of the assembly and of the chassis struts. In addition, it is also possible to incorporate flexible structures.

Parametric models such as one- and two-track models are mathematical substitute models that are essentially based on simple motion equations and can be extended at will.

Regardless of the model type, tire models always represent the

FIGURE 1: **DAIMLER DRIVING SIMULATOR IN SINDELFINGEN**

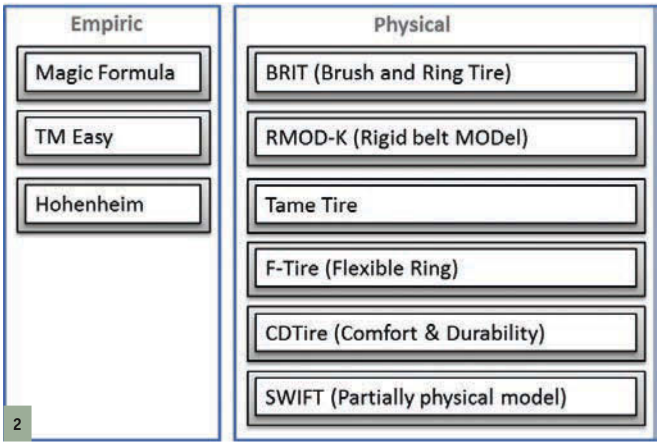


FIGURE 2: **TIRE MODELS**

FIGURE 3: **DAIMLER RIDE SIMULATOR**

FIGURE 4: **DAIMLER DRIVING SIMULATOR WITH MOCK-UP CAR**

important path between the chassis and the road. Mathematically or partially physically parameterized tire models make short calculation times possible. For ride comfort investigations, physical substitute models are also used in addition to these empirical models. They describe in detail in particular the dynamic vibration response of the tires. Figure 2 shows a selection of the tire models employed today.

In addition to tire models, other components are also described in detail by complex models according to the specific situation. Examples of such components include rubber bearings and steering systems, whereby the latter make a decisive contribution to driving behavior due to the controllers implemented in modern systems, with electromechanical support and many input parameters. Steering models today thus include both controllers and implemented friction models and are employed in chassis models by both suppliers and vehicle manufacturers.

Driving behavior is assessed using objective and subjective evaluation criteria. Investigations into how sensitive drivers are to certain influence variables are used to specify criteria that are of relevance to the customer. Complex relationships between visual/acoustic and haptic/kinesthetic perception are difficult to describe objectively, but they can be reliably evaluated by the test driver and reproduced using discrete patterns.

As well as test vehicles, a variety of dynamic driving simulators are employed for kinesthetic simulation of virtual vehicles. Mercedes-Benz research and development has simulators that are among the most advanced of their kind. The Daimler Ride Simulator is used in open-loop mode for the kinesthetic simulation of ride comfort (Figure 3). Driving dynamics closed-loop maneuvers, in particular with haptic feedback to the steering wheel and pedals, are performed in the Daimler driving simulator. This features a mock-up of a real vehicle (Figure 4) in a test room with a 360° projection wall.

A hexapod with six linear actuators moves the dome described. In order to describe the lateral dynamics as accurately as possible, for example during a double lane change, the complete hexapod can be moved transversely by up to 12m at a speed of up to 10m/sec (Figure 1). The simulation models and the test management are controlled from a control room (Figure 5).

Method

For the purpose described here – real-time capable simulation linked to the Daimler dynamic driving simulator – a double-track model based on MATLAB Simulink is used. Input variables are data for geometry, mass and inertia, elastokinematics, spring and ancillary spring rates, damper characteristics, empirical tire models, aerodynamics, specific implemented controllers and other detailed component models as applicable.

Identification is by way of testing and using function data directories. Both MBS and parametric models feature the direct incorporation of tire models, damper identification and aerodynamic measurements. Tests are performed to determine the elastokinematics, steering parameters and moment of inertia/deviation parameters. The identification of vehicle-specific variables such as the unsprung mass is more difficult as it can differ considerably depending on the brakes and wheels used. The basis for the correct parameterization is knowledge of the exact configuration state of the vehicle described. If this differs from the configuration state of the test vehicle, the characteristic curves may have to be modified, which is time consuming and requires appropriate know-how on the part of the user.

Modifications may be made by way of interactive changes to the characteristic curves and input data, based on the digital handling prototypes described in order to achieve the driving dynamics targets. When a setup is found, it is then described by a variation in the kinematics and a change in the bearing stability and implemented in prototypes.

However, with respect to ride comfort investigations, such parametric models are only partially suitable as the dynamic behavior of stability and damping are not explicitly described for every component.

MBS is also an established investigation tool and shares the following as input data with the parametric system: empirical tire models, aerodynamics measurements, controller models and component models.

Rigid kinematics are taken from kinematics plans and elastokinematics are the result of incorporating bearing models. Component-orientated data gathering renders an explicit parameterization of the unsprung masses unnecessary.

Load cases for ride and handling investigations represent the primary areas of application of MBS programs. However, the available test bench tests are also reproduced for the purpose of validation. Experience

FIGURE 5: **DAIMLER DRIVING SIMULATOR CONTROL ROOM**

tells us that this can be calculated to provide reliable predictions, so that MBS includes or calculates all necessary input parameters and characteristic curves for the parametric model.

This data gathering of the parametric model from the MBS thus represents an equivalent branch of input signals and can be used as an alternative to the conventional branch described on the left of Figure 6. The method presented is valid if the two branches do not have differing input data, which would result in large discrepancies in the calculation results of the parametric model. In the form presented, the method has the additional benefit that it provides an early description of virtual prototypes in a parametric system.

Implementation of automated parameterization

As described above, input data for the parametric simulation model is not dependent on the source. MBS results for digital component test benches are converted into an input format identical to that used for the test bench, enabling input files from various data sources to be combined. To this end, source data is apportioned as shown in Figure 7.

Automated parameterization processes should therefore feature the necessary flexibility to selectively gather the individual input data as necessary. This requirement concerns both parameterization paths, so that the systematics are identical, including the graphical user interface.

MBS automatically performs the necessary calculations, controlled by a script. The results files are evaluated, the tables are converted and the specific component models are linked in a step-by-step manner. A standardized GUI is always used as the starting point. Its design is shown in Figure 7.

Daimler dynamic driving simulator

For a subjective assessment of a simulated vehicle, the following sensory channels must be taken into account: visual, auditory, haptic and kinesthetic. The Daimler dynamic driving simulator provides the necessary hardware and control devices for the best possible stimulation of the driver. Visual requirements are satisfied with a 360° display of the vehicle environment. These stable projections are necessary to ensure the optimum orientation. Engine and tire noises enable the driver to gauge the operating state of the vehicle, in particular with respect to wheels that are spinning or raised.

Special attention is given, for example, to the simulation of realistic steering wheel movements that enable reliable predictions, as these are assessed during the maneuver. The electromechanical steering systems employed today, which feature a number of complex regulators, place strict requirements on the description of the steering in the simulation model and in the mock-up. Models that are exclusively based on characteristic curves reach their limits here, so at least a partially physical description of the steering train is necessary. The steering regulator is incorporated as a SIL in cosimulation.

Test drives in dynamic driving simulators can cause nausea due the discrepancy between what is perceived visually and kinesthetically. To make longer test drives possible for large numbers of test persons, the motion system of the simulator must implement the acceleration information from the simulation model as accurately as possible. With the lateral space for movement of the Daimler dynamic driving simulator, transverse acceleration is accurately simulated to satisfy the requirements specified.

In conjunction with validated models, the driving simulator represents an ideal basis for the subjective assessment of a reproducible and realistic vehicle state. A real-time simulation of variants is desirable in order to optimize specific parameters. The two procedures developed for this purpose, which are explained below based on the example of different two-way rigidity and tire models, provide the necessary environment.

The two-way rigidity of the vehicle influences not only the rolling response, but also the axle-specific wheel load differences and thus the resonant self-steering behavior. In the first configuration step, it is sufficient to scale the relevant characteristic curves to the front and rear axles before the qualitative formation of the curve. Here, an appropriate amplification factor is

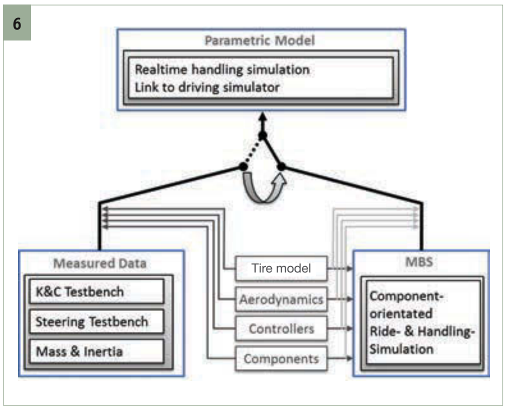


FIGURE 6: **PARAMETERIZATION OF SIMULATION MODEL**

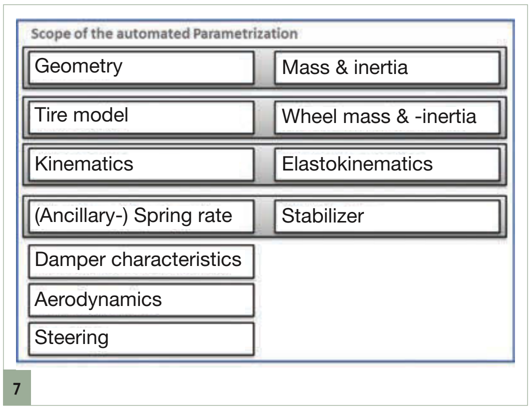
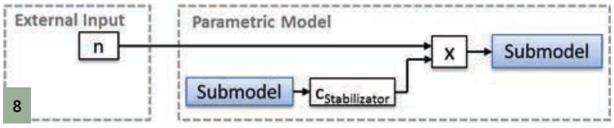
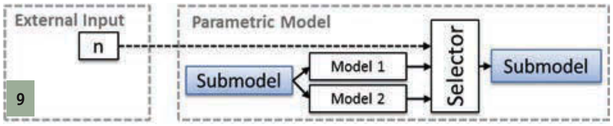
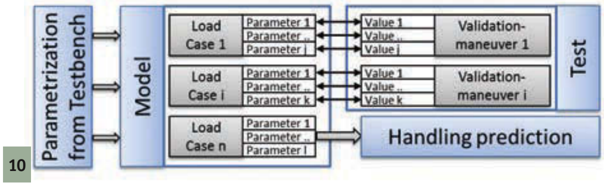


FIGURE 7: **AUTOMATED DATA GATHERING FOR PARAMETRIC SYSTEM**







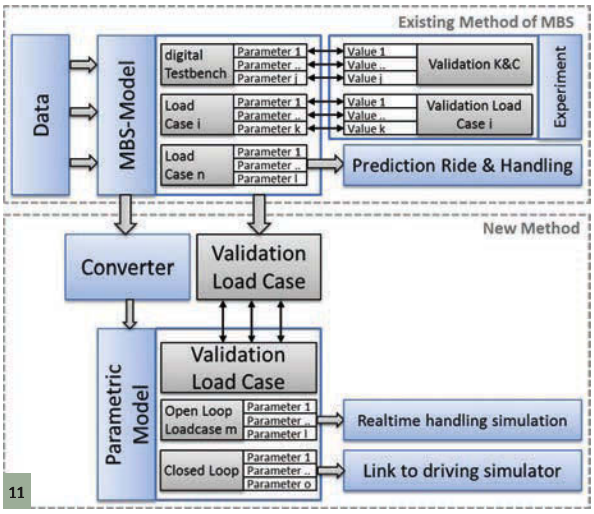


FIGURE 8: **PARAMETER VARIATION ILLUSTRATED BY TWO-WAY RIGIDITY**

FIGURE 9: **VARIATION OF COMPONENT MODELS**

FIGURE 10: **VALIDATION METHOD FOR PARAMETRIC SIMULATION MODELS**

FIGURE 11: **VALIDATION METHOD USING VALID MBS MODEL**

added to the model (Figure 8) and diverted as an external parameter that can be varied at will by the operator of the driving simulator while a maneuver is in progress. This method is possible and has been implemented for all scalable variables.

In the case of non-scalable factors, and with several component models, the variants to be assessed are loaded in parallel for on-the-fly conversion. The changeover between the variants is executed with an external input (see Figure 9). Such a procedure is to be used, for example, for tire models. In order to change the model at any time, the passive variant is calculated continuously in the background.

In all cases, discontinuities in the signal curves are to be avoided as they could cause noticeable acceleration. Because of this, a ramp-type transition of output signals has been implemented for each changeover of variants.

Validation of method

To validate parametric simulation models, reference load cases are used in dynamic driving tests. Precise information about the quality of the predictions delivered by the simulation models is based on reliably reproducible maneuvers. This counters the need for a large number of repeat drives for statistical validation made necessary due to mean scattering. Another limiting parameter is the choice of available sensor signals. While all signals are available for every component in the simulation model, the efficient, non-reactive installation of sensors in test vehicles is subject to far greater complexity. A selected set of reference load cases with a limited selection of measuring variables is available for validating parametric models using current methods (see Figure 10).

In the case of automated parameterization using MBS, as presented here, validation is based on virtual test drives. The depth of the data gathered is greatly reduced compared with the highly complex MBS models with flexible structures. Should this cause large discrepancies between the results, it can be accurately assigned to specific components. Moreover, automated validation is possible, making for efficient model validation in addition to the automated data-gathering process described earlier.

Figure 11 illustrates the established parameterization and validation process for the MBS method and the incorporation of the supplementary method. Employing the parametric calculation models already validated using MBS (which provides for reliable predictions), it is thus possible to perform real-time calculations of handling load cases and kinesthetic simulations on the driving simulator early in the development phase.

The validation method described using a validated MBS model has been proved in tests with different types of physical reference vehicles (van, sedan, SUV). Further continuous validation is conducted parallel to the process.

Conclusion

The method presented achieves an additional benefit with no major expense. Efficiency is boosted by the use of real-time-capable calculation tools, and target values for multibody simulation are generated from the findings from these calculations and virtual configuration drives, allowing component-orientated parameters to be optimized at an early stage. Similarly, the method makes investigations into detailed component models possible in white-box chassis models with reduced complexity.

The benefit is not just in the parametric model and its extended and earlier application. Additional benefit can also be identified in multibody simulation models due to the closed-loop subjective assessment of component variants on the driving simulator. As described earlier, the objectivization of driving impressions remains an element of diverse research activities and is today not a complete substitute for subjective assessment.

The method presented permits fast and efficient development and reduces the number of physical prototypes needed in the early phases.

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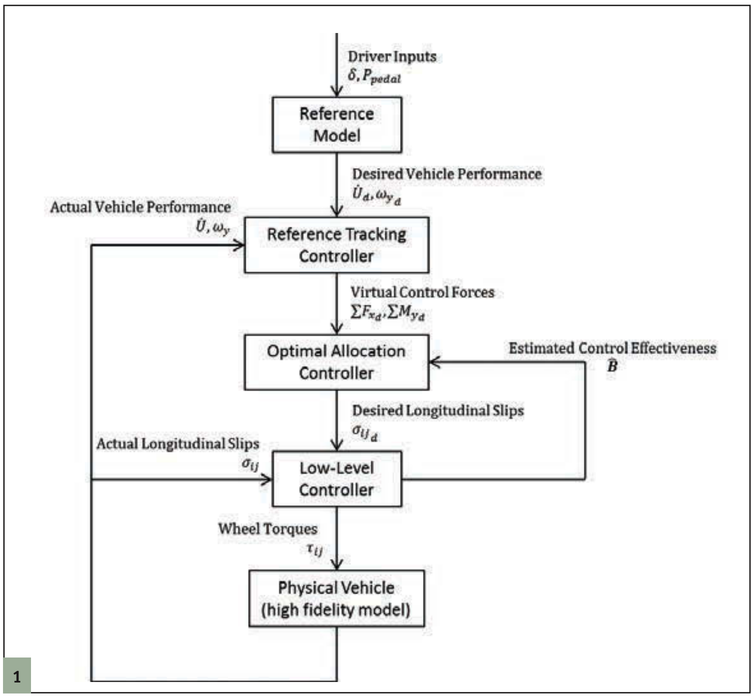
Electrified vehicle powertrains are becoming prevalent due to their high efficiency and capability of utilizing fuel sources alternative to petroleum. These electrified powertrains can be configured so that electric motors independently drive both front wheels, both rear wheels, or even all four wheels. Such a configuration is termed a wheel-motored vehicle. This can be accomplished by mounting the electric motors to the sprung mass and transferring their power via conventional axle shafts, or by mounting the electric motors directly to the unsprung mass, termed a hub-electric motor. Regardless of the configuration adopted, the use of independent electric wheel motors not only allows for improvements in vehicle efficiency, but has the potential to revolutionize active handling and safety control.

Traditionally, active stability and handling interventions are actuated by reducing engine power and modulating individual electrohydraulic brakes. Compared with these conventional actuators, the electric motor presents many merits. Electric motors can generate both driving and braking torque, which allows for the generation of maximum yaw moment without impacting longitudinal velocity. Additionally, electric motors can respond 10 times more quickly than electrohydraulic brake systems. Finally, unlike electrohydraulic brake and engine systems, the torque output by the electric motor can be estimated with high accuracy. This final merit is extremely beneficial as it can provide additional information regarding the interaction between the vehicle's tires and the road surface.

This article will present a control philosophy that takes advantage of these merits to improve the handling and stability of future vehicles.

The wheel-motored vehicle is generally over actuated, i.e. it has more actuators than control goals. An optimal control allocation technique is proposed to take advantage of this, achieving performance goals while avoiding tire saturation. The control effectiveness matrix of the optimal control law is adapted based on real-time estimates of tire stiffness. These stiffness estimations are generated using the known torque generated by the wheel motors and wheel speed measurements. This article will describe the components making up the block diagram of the proposed control philosophy shown in Figure 1 and present some performance

FIGURE 1: **SYSTEM BLOCK DIAGRAM**



> "Regardless of the configuration adopted, the use of independent electric wheel motors not only allows for improvements in vehicle efficiency, but has the potential to revolutionize active handling and safety control"

results obtained using the CarSim vehicle simulation software integrated with MATLAB's Simulink.

Reference model and reference tracking controller

The reference model is critically important in the design of a control system. It is responsible for generating desired system performance based on inputs from the user. In this structure, the reference model accepts the steering wheel angle (δ) and accelerator/brake pedal position (P_{pedal}) inputs from the driver, and outputs the desired yaw rate (ω_{yd}) and longitudinal acceleration ($\dot{U}_d$). A 2DOF bicycle model of planar vehicle dynamics was selected to generate the desired yaw rate signal based on steering wheel angle and longitudinal velocity. Desired longitudinal acceleration was programmed via a look-up table of pedal positions.

The objective of the reference tracking controller is to minimize the error between the desired vehicle performance ($\dot{U}_d$, ω_{y_d}) and the actual measured vehicle performance ($\dot{U}$, ω_y). Longitudinal acceleration ($\dot{U}$) is measured with an accelerometer and yaw rate (ω_y) is measured by a gyroscopic sensor, both of which are installed on modern automobiles. The reference tracking controller drives the actual vehicle performance toward the desired vehicle performance by modulating virtual control forces. A proportional integral controller is utilized, although any controller capable of robustly driving the error toward zero can be considered.

Optimal allocation controller

The two virtual forces modulated by the tracking controller are total longitudinal force (ΣF_x) and total yaw moment (ΣM_y). The term 'virtual' is used because there are no actuators installed on the vehicle to directly inflict these forces and moments upon the vehicle. Instead, they will be generated indirectly by appropriately modulating the motor torques on the four tires of the vehicle. Tires generate longitudinal force as a function of slip ratio (σ). Slip ratio is defined as

$$\sigma_{ij} \approx \frac{R\omega_{ij} - V_{x,ij}}{V_{x,ij}},$$

where R represents the wheel radius (assumed the same for all tires); ω_{ij} represents the angular velocities of the wheels; and $V_{x,ij}$ represents the longitudinal velocities of the wheel centers. The subscripts $ij = \{lf, rf, lr, rr\}$ represent each individual wheel. Figure 2 provides an example of longitudinal force generation versus slip ratio for a tire operating on roads with varying surface. Coefficients of friction ($\mu_{max} = \{0.2, 0.5, 0.8\}$) approximately represent icy pavement, wet pavement and dry pavement, respectively.

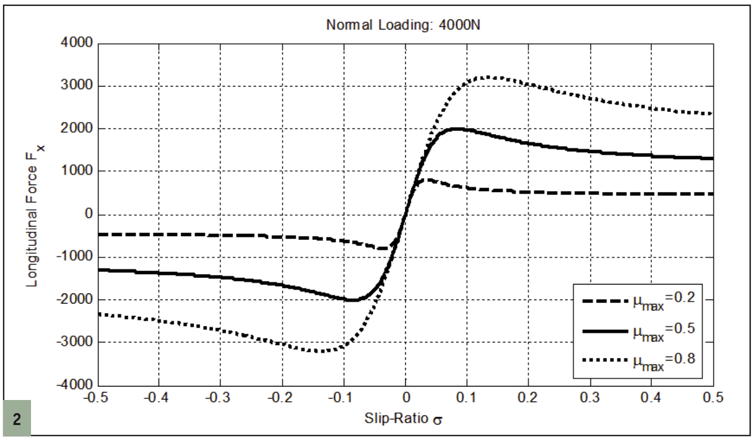


FIGURE 2: **EXAMPLE OF LONGITUDINAL TIRE FORCE GENERATION**

Regardless of road surfaces, the relationship between force generation and slip ratio is approximately linear for small slip ratios. At higher slip ratios, force generation begins to saturate and decay. It is important to avoid this region of saturation as it degrades longitudinal force generation and accelerates tire wear. In addition, the ability of the tire to generate lateral forces is greatly compromised when the tire operates with excessive slip ratio. For these reasons, it is desirable to operate the tire at slip ratios in the region of linear force generation. An optimal allocation controller is proposed to achieve the virtual forces requested by the reference tracking controller, while constraining tire slip ratios within their linear region of operation. The allocation controller selects desired slip ratios for each corner of the vehicle, which are then achieved by the slip ratio controller, as will be discussed in the next section.

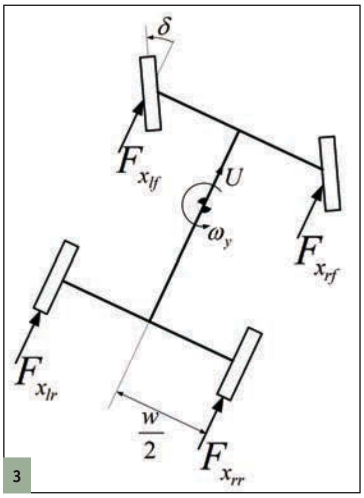


FIGURE 3: **VEHICLE FORCE DIAGRAM**

Figure 3 shows the top-down view of a simplified vehicle. Assuming that the steering angle (δ) is small, the virtual longitudinal force and yaw moment are represented below.

$$\Sigma F_x = F_{x_{lf}} + F_{x_{rf}} + F_{x_{lr}} + F_{x_{rr}}$$

$$\Sigma M_y = \frac{w}{2}\left(F_{x_{rf}} + F_{x_{rr}} - F_{x_{lf}} - F_{x_{lr}}\right)$$

Assuming that the tire is operated within the linear region of force generation, longitudinal force can be approximated by:

$$F_{x_{ij}} \approx \hat{C}_{ij}\sigma_{ij}$$

where C_{ij} represents the estimated slope of Figure 2 for each tire. With this approximation, the virtual force equations can be expressed in matrix form as shown below. The virtual forces are represented in vector $\boldsymbol{v}$ and desired slip ratios in vector $\boldsymbol{u}$. Matrix $\boldsymbol{B}$ is the control effectiveness matrix. $\boldsymbol{B}$ is a fat matrix, meaning that there are more control outputs than control goals. The system is thus over-actuated, allowing the virtual forces to be achieved by an infinite combination of desired slip ratios. This allows for additional control goals to be expressed in an optimization framework, reducing the degrees of freedom of the problem so that a unique solution can be generated.

$$\begin{bmatrix}\Sigma F_x \\ \Sigma M_y\end{bmatrix} = \begin{bmatrix} C_{lf} & C_{rf} & C_{lr} & C_{rr} \\ -\frac{w}{2}C_{lf} & \frac{w}{2}C_{rf} & -\frac{w}{2}C_{lr} & \frac{w}{2}C_{rr}\end{bmatrix}\begin{bmatrix}\sigma_{lf_d} \\ \sigma_{rf_d} \\ \sigma_{lr_d} \\ \sigma_{rr_d}\end{bmatrix} \rightarrow \boldsymbol{v} = \boldsymbol{B}\boldsymbol{u}$$

FIGURE 4: **DESIRED AND ACTUAL VEHICLE PERFORMANCE**

FIGURE 5: **DESIRED SLIP RATIOS FROM ADAPTIVE AND STATIC OPTIMAL ALLOCATION CONTROLLERS**

The cost function (J) to be minimized by optimization is represented in the equation below. The first term of the equation contains the Euclidean norm of the error between desired and allocated virtual forces. $\boldsymbol{W}_v$ is a weighting matrix that is used to penalize the errors in the virtual forces independently. The second term of the equation contains the Euclidean norm of control effort, with $\boldsymbol{W}_u$ allowing penalization of independent slip ratios. λ is used to weight the relative importance of the different objectives expressed in the first and second terms in the cost function. Basically, minimization of this cost function attempts to achieve the desired virtual forces, while minimizing the slip ratio of independent wheels.

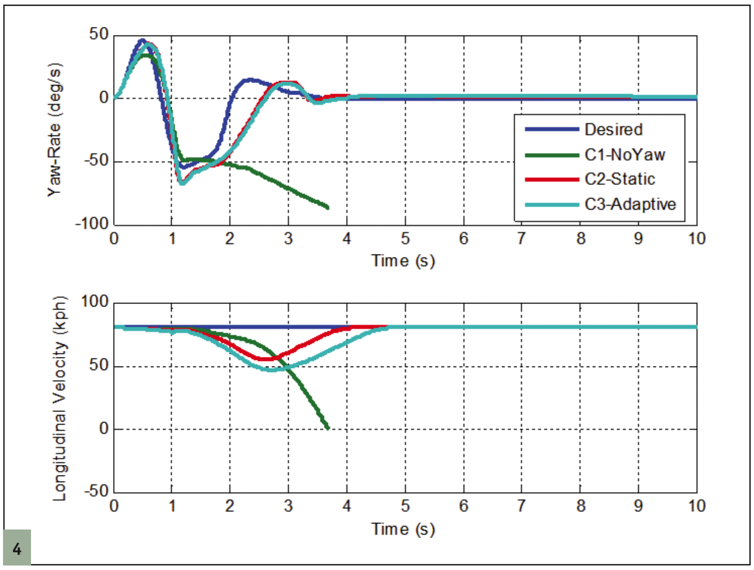
$$J = \|(\boldsymbol{B}u - v_d)^T \boldsymbol{W_v} (\boldsymbol{B}u - v_d)\|_2^2 + \lambda \|u^T \boldsymbol{W_u} u\|_2^2$$

The cost function is then rearranged into a form suitable for quadratic programing, as shown below.

$$J = \frac{1}{2} u^T H u + u^T f,$$

$$where\ H = 2[\boldsymbol{B}^T \boldsymbol{W_v} \boldsymbol{B} + \lambda \boldsymbol{W_u}], f = -2\boldsymbol{B}^T \boldsymbol{W_v} v_d$$

A merit of quadratic programing is the availability of robust algorithms that can generate optimal, or near-optimal, solutions while satisfying explicit constraints. The constraints imposed upon this optimization problem are that the slip ratio of each tire should be bounded by prescribed minima and maxima. The Hildreth's Quadratic Programming procedure was utilized to solve the described optimization problem, as it guarantees convergence within a relatively small number of iterations. The quadratic programming problem is solved at every control iteration in order to determine the optimal slip ratios (u) needed to generate the desired virtual forces (v). As a result, coefficients within the control effectiveness matrix ($\boldsymbol{B}$), as well as the maximum and minimum allowable slip ratio constraints for each tire, can be updated to reflect the current operating state of the vehicle.

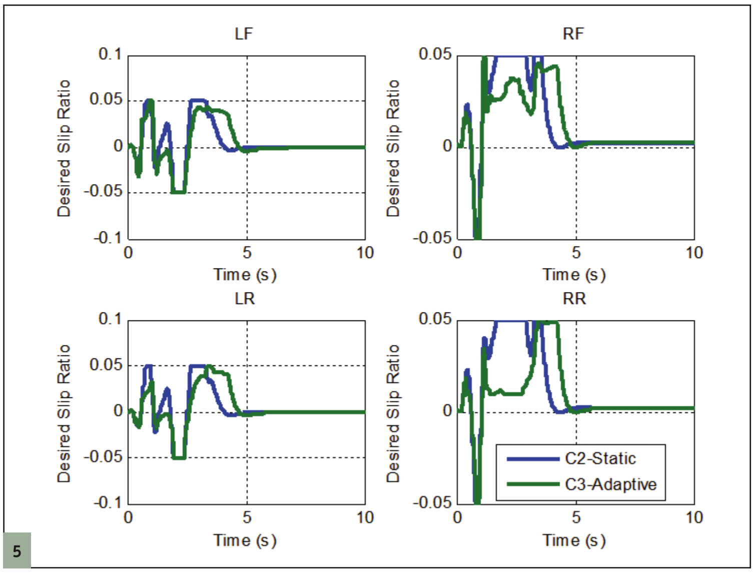


Low-level controllers

The output of the optimal allocation controller is the desired slip ratio of each wheel (σ_{ij_d}). The low-level controller is tasked with generating the wheel motor torques (τ_{ij}) to achieve these desired slip ratios, and secondarily to estimate the resulting longitudinal force generated by each tire. Wheel dynamics can be modeled simply in the below equation:

$$J_w \dot{\omega}_{ij} = \tau_{ij} - RF_{x_{ij}}$$

where J_w and R represent the rotational inertia and radius of the wheel. The rate of change of wheel speed ($\dot{\omega}$) is the result of torque injected into the system by the wheel motor (τ), and the resultant torque from the longitudinal tire force (RF_x). The motor torques and wheel speeds of a wheel motored vehicle can be easily estimated; thus, the longitudinal force can be straightforwardly estimated from the equation of wheel dynamics. The disturbance observer framework is used to estimate longitudinal tire force, and explicitly reject its effect during the control of slip ratio. Using proportional integral slip ratio feedback controllers and explicitly rejecting RF_x in the control law, the low-level controller quickly and accurately tracks desired slip ratio commands, and generates a real-time estimate of longitudinal tire force.



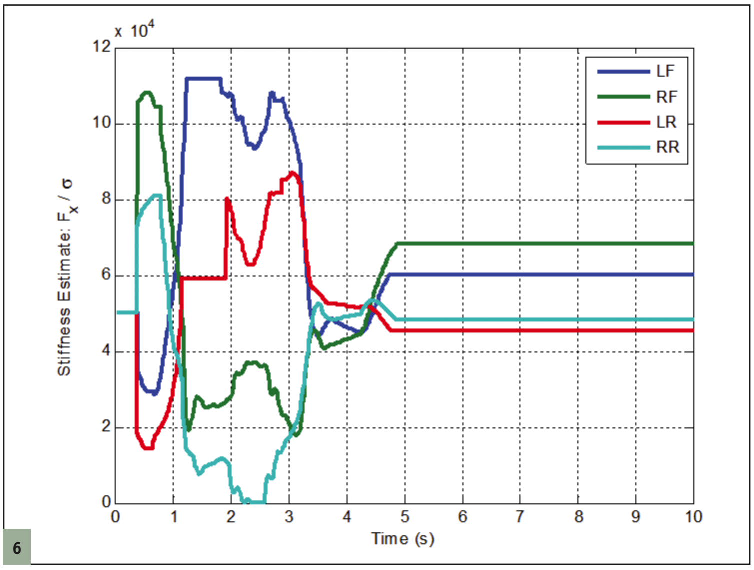
"By avoiding excessive slip ratio on saturated tires, the strategy allowed them to generate larger lateral force, resulting in a tighter turn. This is desirable for obstacle avoidance as well as in performance-handling situations"

Adaptation

Using the estimates of longitudinal tire forces generated by the low-level controllers, the tire stiffnesses are estimated as shown below.

$$C_{ij} = \frac{F_{x_{ij}}}{\sigma_{ij}}$$

These tire stiffness estimates are used to update the control effectiveness matrix ($\boldsymbol{B}$) used by the optimal allocation controller. Adapting the control effectiveness



closely than the adaptive controller C3. However, this marginal tracking improvement was accomplished by requesting control effort from already saturated tires, which has the potential of driving the vehicle to instability depending on the available road surface friction.

Figure 5 shows the slip ratios desired by the non-adaptive and adaptive optimal allocation controllers for vehicles controlled by controllers C2 and C3. Areas where the slip ratio desired by C3 differs from C2 correspond with instances of low estimated tire stiffness, shown in Figure 6. This phenomenon is particularly pronounced in the right rear tire. Between $t = [1,3]$ seconds, the tire is lightly loaded and exhibits low stiffness. During this time the non-adaptive allocation controller, unaware of the current operating state of the tire, requests a maximum slip ratio of 0.05. Conversely, the adaptive allocation controller, penalizing the use of low-stiffness tires, does not request notable slip ratio from the tire until a time when its stiffness has increased.

The benefit of the adaptive control strategy is evident in Figure 7, where the trajectory of vehicles controlled by C2 and C3 are compared. By avoiding excessive slip ratio on saturated tires, the adaptive control strategy allowed tires to generate larger lateral force, resulting in a tighter turn. This is a desirable quality for emergency obstacle avoidance, as well as performance-handling situations.

FIGURE 6: **ESTIMATED LONGITUDINAL STIFFNESS USED BY ADAPTIVE OPTIMAL ALLOCATION CONTROLLER**

FIGURE 7: **TRAJECTORY OF ADAPTIVE AND STATIC CONTROL STRATEGIES**

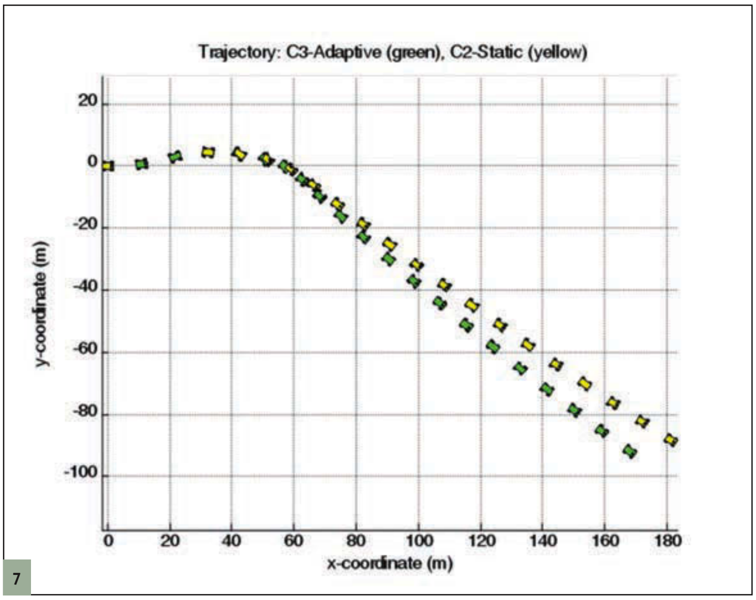
allows the optimal allocation controller to make slip ratio requests that are dependent upon the current force-generating characteristics of the tires. This improves the accuracy with which the desired virtual forces are achieved.

Referring back to Figure 2, it is evident that a tire operating within the linear region of force generation will have high stiffness, while a tire operating beyond the linear region will have lower stiffness. Operation beyond this linear region not only degrades longitudinal force generation, but greatly degrades lateral force generation. This is undesirable for vehicle handling and safety, and should be avoided. To further discourage operation in this region, controller allocation to tires with lower estimated stiffness can be increasingly penalized within the $\boldsymbol{W_u}$ matrix. Additionally, the maximum desired slip ratio of saturated tires can be reduced in the constraint equation of the optimal allocation controller.

Simulation study

Three control systems were applied to a vehicle modeled in CarSim vehicle dynamics simulator. The goal of each control system was to sustain a vehicle speed of 80km/h while excited by an aggressive steer-dwell driver steering input. The first controller, C1, is designed such that no attempts are made to track the desired yaw rate. This is done for the sake of comparison. Other controllers C2 and C3 are both designed to track the desired yaw rate, which was generated by a linear 2DOF bicycle model. In controller C2, the control effectiveness matrix ($\boldsymbol{B}$), and the effort penalty matrix ($\boldsymbol{W_u}$) are kept constant within the optimal allocation controller. Lastly, the elements of the matrices used in controller C3 are adaptively modulated as described previously.

Figure 4 shows the comparison of the responses due to the three controllers with respect to a desired response. The maneuver was aggressive enough to cause the vehicle to lose control and spin out without yaw rate tracking. The vehicles equipped with controllers C2 and C3 exhibited similar performance, maintaining stability throughout the maneuver. The vehicle with the non-adaptive controller, C2, tracked longitudinal speed slightly more



New direction

ELECTRIC MOTORS OFFER NEW POSSIBILITIES FOR TORQUE VECTORING, BUT **HENNING OLSSON** OF OPTIMUMG SAYS THAT THE IMPACT OF SUCH SYSTEMS ON TIRE PROPERTIES MUST BE ADDRESSED

Torque vectoring – which entails controlling the distribution of driving and braking force between two or more wheels to achieve safety and handling objectives – has been around since the dawn of automobiles through the use of differentials. Electronic stability control systems and active differentials introduced in the past two decades have greatly increased vehicle dynamicists' ability to more freely control the distribution. With multiple electric drive motors becoming more commonplace, the scope for torque vectoring has grown substantially. Admittedly, it is not the active control of the force distribution that has made these systems so popular in the past, but rather the effect the force distribution has on a vehicle's yaw dynamics.

On a four-wheeled vehicle, eight tire forces and four tire moments, acting around the center of gravity of the vehicle, result in a yaw moment. This induces a yaw acceleration that makes the vehicle change direction. ESC systems aid the driver in controlling the vehicle by modulating brake pressures on individual wheels, which in turn result in a changed yaw moment, yaw acceleration and ultimately a changed yaw rate and direction of the vehicle. A major benefit with using electric motors in this situation is that both driving and braking torques can be generated, increasing the range of yaw moments that can be achieved. This process can also be made very energy efficient since energy recovered on one motor can be used to drive another (in the case of ESC systems, energy is wasted as it is converted to heat in the brake system). The more precise torque control that electric motors offer means that the car's yaw dynamics can be controlled seamlessly, all the way from on-center to 'limit' operation (Figure 1).

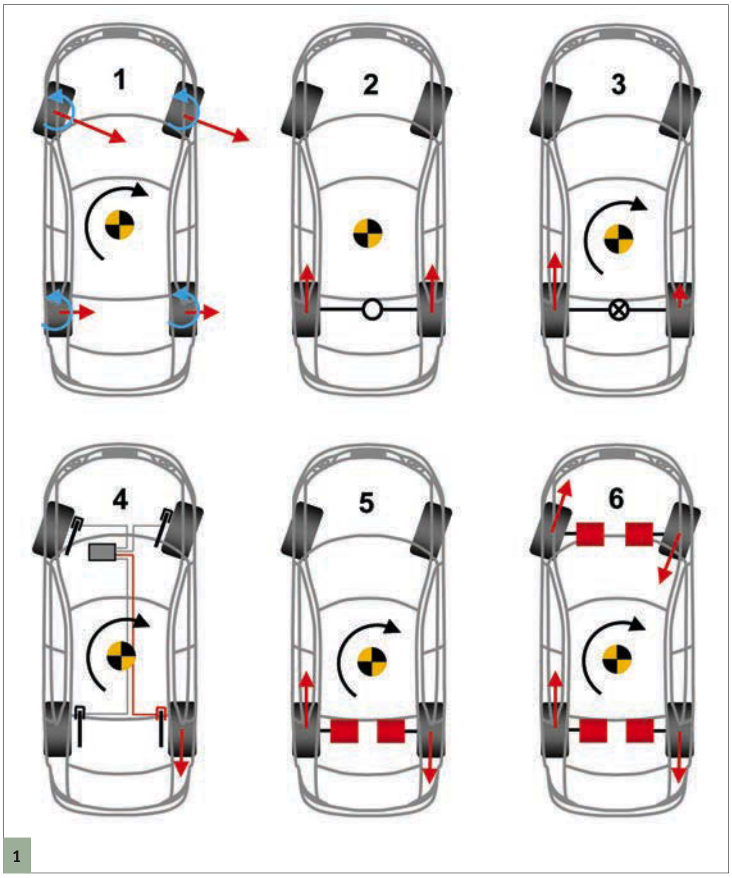


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FIGURE 1: WAYS OF GENERATING YAW MOMENT:
1. THE TIRES' LATERAL FORCES AND SELF-ALIGNING TORQUES CAN GENERATE A YAW MOMENT
2. AN OPEN DIFFERENTIAL WILL NOT GENERATE ANY YAW MOMENT
3. AN ACTIVE OR LIMITED-SLIP DIFFERENTIAL CAN GENERATE A YAW MOMENT
4. AN ESC SYSTEM CAN USE THE BRAKE SYSTEM TO CREATE A YAW MOMENT
5. AN ELECTRIC VEHICLE WITH TWO ELECTRIC MOTORS CAN GENERATE A YAW MOMENT
6. AN ELECTRIC VEHICLE WITH FOUR ELECTRIC MOTORS CAN GENERATE A YAW MOMENT

FIGURE 2: TORQUE VECTORING CAN HAVE A TREMENDOUS EFFECT ON THE HANDLING OF A CAR

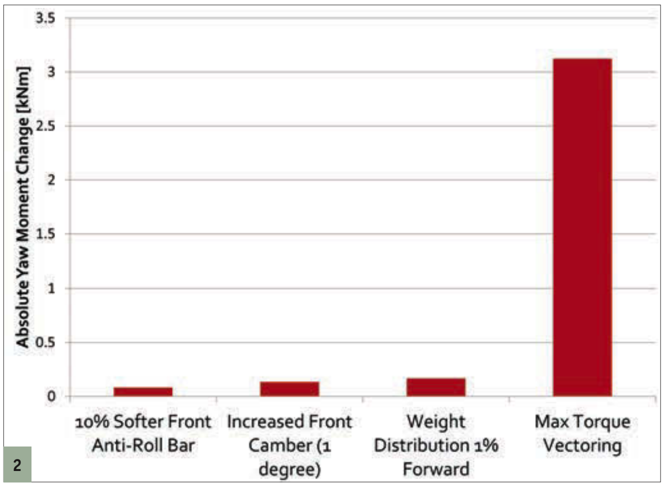
FIGURE 3: THE FRONT AXLE IS MORE EFFECTIVE AT GENERATING UNDERSTEERING YAW MOMENTS, WHILE THE REAR AXLE IS MORE EFFECTIVE AT GENERATING OVERSTEERING YAW MOMENTS

FIGURE 4: THE TIRE'S FRICTION ELLIPSE HIGHLIGHTS THE LIMITATIONS OF THE PNEUMATIC TIRE. HERE THE RAW TIRE DATA FROM A TIRE TESTING MACHINE IS OVERLAID ON THE TIRE MODEL USED IN THE SIMULATION

New approach to handling

Tuning the handling of a vehicle normally includes adjusting three parameters: the distribution of vertical loads on tires, through mass distribution, springs, dampers and anti-roll bars; tire alignments such as camber and toe, through elasto-kinematic properties; and tire force and moment characteristics, through tire construction and inflation pressure. Changing these parameters alters the distribution and magnitudes of the tires' forces and moments, resulting in a change in yaw moment.

Using OptimumDynamics vehicle dynamics simulation software, a mid-size passenger car with two electric motors on the rear axle (each rated at 500Nm), was simulated to evaluate how the effect of these traditional tuning parameters compares with the possibilities of torque vectoring



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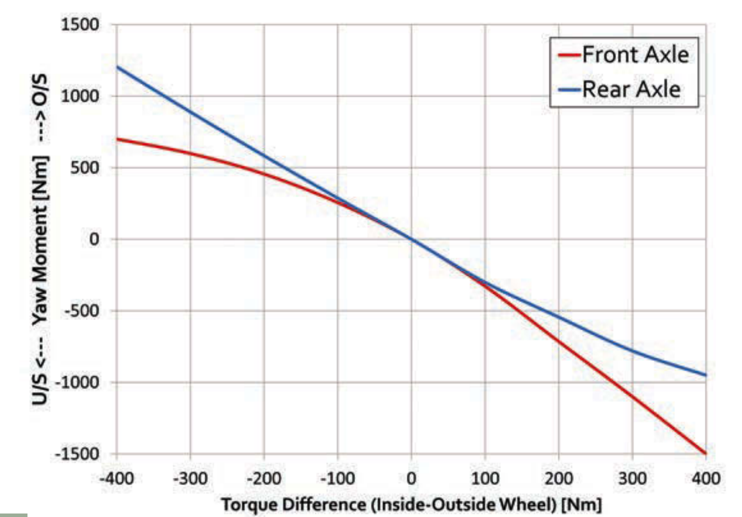

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(Figure 2). The effects on yaw moment during cornering with different chassis changes compared with torque vectoring highlights the possibilities that lay ahead. Theoretically, the effect that torque vectoring has on handling is a magnitude larger than other typical chassis parameter changes. This indicates that torque vectoring could be used as the primary tuning tool for car handling.

Much of the research on torque vectoring focuses on the control algorithms required to determine how the driving and braking torques should be distributed at any given time – effectively interpreting what the driver wants the vehicle to do. No matter the type of control algorithm used, it would typically only require a few lines of software code to change the torque vectoring behavior and subsequently the vehicle's handling characteristics. This methodology is successfully used in the aerospace industry, where variable-stability aircraft use a range of control algorithms for flight control surfaces (such as rudders and ailerons) to achieve vastly different flying behaviors. Having the handling characteristics of a car change from those of a minivan to those of a sports car in the matter of seconds would be of limited use for the everyday driver. The potential applications are in vehicle dynamics development and cost reduction.

Chassis setup by software

With torque vectoring being capable of greatly changing the handling of a vehicle, many of the compromises that vehicle dynamicists face between ride and handling are eliminated.

Selecting suspension components, such as tires, bushings and dampers, to meet comfort targets as well as performance targets is seldom an easy task. With torque vectoring it is possible to select much of the hardware based on ride specifications and then rely on torque vectoring to meet handling and performance goals.

This philosophy can be extended. For example, vehicles

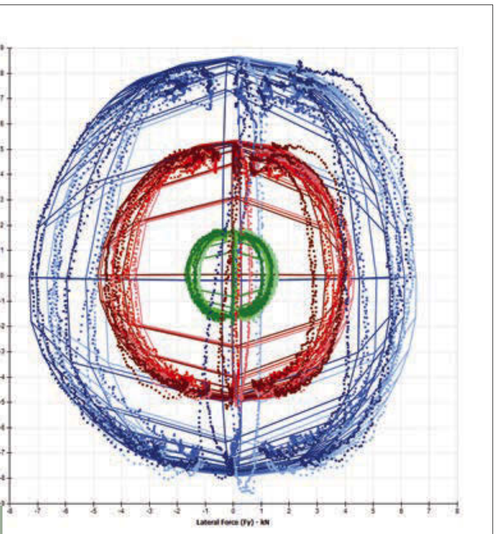
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FIGURE 5: **WHEN A TIRE IS NOT FREE-ROLLING (SR ≠ 0.0%), THE LATERAL FORCE CAPABILITIES OF THE TIRE ARE REDUCED**

FIGURE 6: **THE EFFECTS OF TORQUE VECTORING CAN BE SEEN IN THESE SIMULATION RESULTS. HIGHER SLIDING ENERGIES IN MID-CORNER SITUATIONS HIGHLIGHT HOW THE TORQUE VECTORING IS USED TO CONTROL THE YAW RATE**

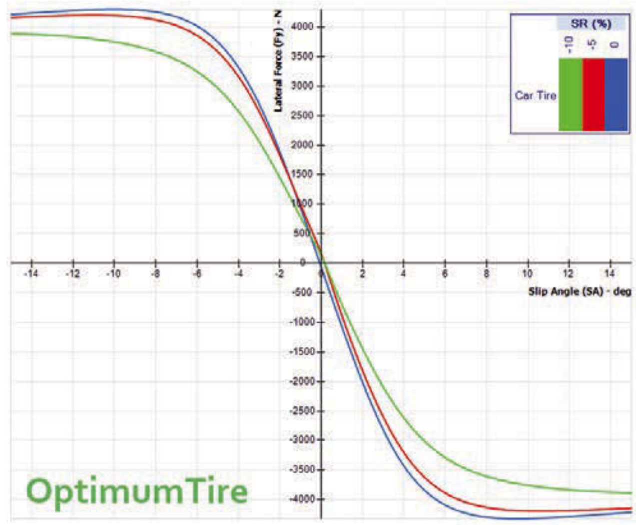
with undesirable weight distributions or inertias stemming from packaging compromises can still be made to handle properly. This can open the possibility for vehicle layouts that are unfeasible from a traditional vehicle dynamics perspective but are desirable from design, safety, utility or packaging perspectives.

From a cost perspective, using torque vectoring to reach handling goals means that all trim levels of a model, from entry level to high performance, can all use the same vehicle dynamics hardware. This reduces variants and simplifies manufacturing, resulting in overall savings. From a vehicle dynamics perspective, the only differentiator between versions would be a different tuning of the torque vectoring system, resulting in anything between a dull driving experience to very sporty handling characteristics. OEMs have successfully used similar approaches to differentiate engines by achieving different power outputs through software, while keeping most of the hardware identical.

Torque vectoring might appear to be a great prize for vehicle dynamics, but even though it has great potential there are a number of challenges ahead. One of them is the tires, responsible for converting the drive and brake torques from the drivetrain to longitudinal contact-patch forces.

Tires – a key player

Going back to the simulation study, the effects of torque vectoring on the front or rear axle can be evaluated. Differences between the axles can be observed by seeing how much yaw moment can be generated for a given torque split between inside and outside wheel (Figure 3). One conclusion that can be made is that torque vectoring on the front axle is better at generating understeer (a lack of yaw moment), whereas torque vectoring on the rear is better suited for generating oversteer (too much yaw moment).



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The reason for this can be explained by the tires' force and moment properties. For a tire to generate longitudinal forces, it needs to slip longitudinally (slip ratio), which leads to a reduction in lateral forces (Figure 4). When torque vectoring takes place on an axle, the lateral grip of that axle is reduced. When trying to generate oversteer by torque vectoring on the front axle, the longitudinal forces will create an oversteering yaw moment. But at the same time, the lateral grip of the axle is reduced due to the increased slip ratio (Figure 5), resulting in a decreasing yaw moment (causing understeer). Even though the net yaw moment results in more oversteer, the efficiency is reduced.

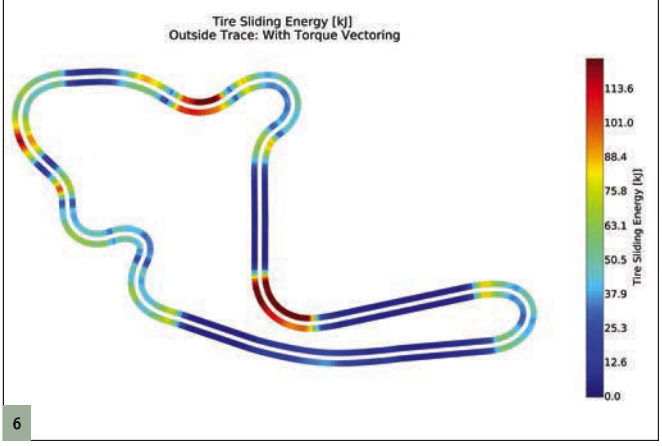
Other aspects to consider are tire energy efficiency and tire wear and how they are affected by torque vectoring. A tire needs to slip to generate forces; when that happens energy is dissipated as heat, reducing the overall energy efficiency of the vehicle through increased frictional losses. Research has also shown that the tire sliding energy correlates well with tire wear rates. Extensive use of torque vectoring would thus increase the vehicle's energy consumption and accelerate the wear of the tires.

To fully understand the effects of torque vectoring on tire wear, a simulation of a high-performance car around a racetrack was performed. The total tire sliding energy for all four tires was calculated with and without torque vectoring (Figure 6). The results showed that torque vectoring increased the tire sliding energy by 19%, leading to a major increase in tire wear.

One solution to reduce this problem would be to use tires with increased slip stiffness (less slip required to generate the same force). Achieving an increase typically requires changes to the tire construction that would also increase the vertical stiffness of the tire, leading to worse ride and durability properties of the tires. Clearly there are opportunities for tire manufacturers to develop new designs that are more suitable for torque vectoring applications.

Conclusion

Electric torque vectoring has the potential to serve as a great tool in the vehicle dynamicist's toolbox by partly decoupling the requirements for ride and handling while opening the door for cost savings. But there are also a multitude of challenges ahead, stretching past electric motors and batteries. Tires play a major role and increased tire wear is a major concern, which will require focused development efforts from tire manufacturers. Torque vectoring also has the potential to mask poor handling characteristics, but at the expense of increased tire wear and reduced energy efficiency.



6

Twin power

JOHN O'BRIEN CHECKS OUT HYUNDAI-KIA'S SELDOM SEEN NAMYANG PROVING GROUND TO HEAR ABOUT VEHICLE DYNAMICS DEVELOPMENT, KOREAN-STYLE

MAIN: **THE NAMYANG COMPLEX FEATURES 30 TEST TRACKS AND COMPREHENSIVE R&D LABORATORIES**

The Korean automotive industry is currently booming, but the picture hasn't always been so rosy. A national recession just before the turn of the century saw some domestic automotive manufacturers being bought out – as with GM's acquisition of Daewoo.

Hyundai and Kia survived by merging, and have since built an impressive reputation for quality, style and – increasingly – driving dynamics. Central to all new model development is the joint Namyang Research and Development Center. Situated some 30 miles south of Seoul, the expansive 167ha center houses every facility needed to develop a car from scratch, and is built around a comprehensive proving ground.

The network of over 30 roads that make up the proving ground accounts for over 60% of Namyang's total size, and breaks down further into 70 individual surfaces and road types. At the very center of the facility is the 'multipurpose' road, measuring 1.2km long and 70m wide, which is the main test road for Hyundai-Kia's engineers. It is where brake, ride, compliance and various other dynamic tests are primarily conducted alongside a rigorous benchmarking program; at any given point, there are more than 350 rival manufacturers' cars on site.

According to Chung-Yul Hwang, vice president of the mid-large vehicle project center, the two brands benchmark each model against direct rivals, from specific markets. "We try to keep our eyes on newcomers as well as market leaders," he says. The Porsche Cayman S and Toyota GT86, nestled among the array of German sedans at the time of our visit, are perhaps indicative of things to come.

In accordance with Hyundai and Kia's increased global popularity, the test site also houses a long stretch of road split into seven separate surfaces, recreating roads from key markets. In addition to the 'Seongbuk-Dong'-type road – typical of the road surface found in an exclusive part of the nation's capital – there are many more

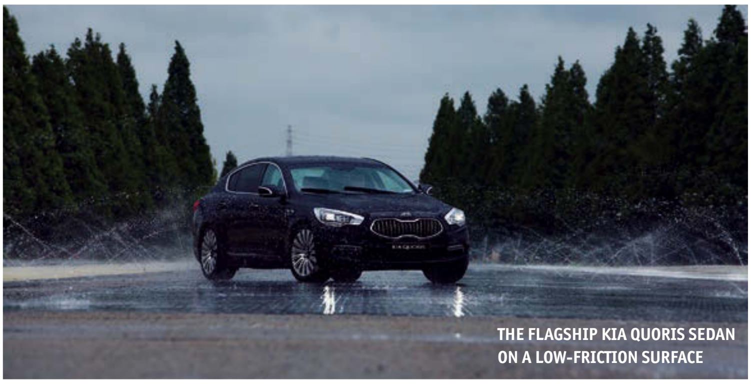
BEYOND NAMYANG

In addition to the main research and development center, Hyundai-Kia also operates a further three proving grounds. Its 66ha site in Ulsan, Korea, was the country's first proving ground when it opened in 1984, and features a further 19 test routes and an additional high-speed ring. To the south of Namyang lies Hwaesong proving ground. Completed in 1993, the facility offers a third high-speed track and 16 further test routes.

Depending on the vehicle, the company's R&D centers in Europe and the USA can take responsibility for the localization of a specific product. "Local feedback from Europe and the USA is carefully reviewed by the R&D center in Korea and reflected in future developments," according to Chung-Yul Hwang.

Key to the localization process are local test facilities; Hyundai-Kia's latest proving ground is in the Mojave Desert, California. Constructed at a cost of US$60m, the vast site is over 10 times the size of Namyang, totaling 1,750ha, and is the third-largest non-domestic-manufacturer proving ground in the USA. With over 116km of road network and a 10.4km high-speed oval, the site offers a unique expansion to Hyundai-Kia's test facilities, as well as insight into its biggest market.

Europe, too, has a unique offering, by way of a newly built development center alongside the iconic Nürburgring, Germany (*below*). Thomas Oh, EVP & COO of International Business Development at Hyundai-Kia, recently stated that the 'European dream' for Kia was the Cee'd, and that Namyang is working closely with Kia Motors Europe on the next iteration of this model, so the new facility is likely to play an increased role in future model development.



THE FLAGSHIP KIA QUORIS SEDAN ON A LOW-FRICTION SURFACE

replications, including a cracked and potholed tarmac surface imitative of UK road conditions, and a long-wave-pitch road that replicates the USA's Pacific Coast Highway. Used to ensure a uniform ride quality and noise levels across all models, the road sees over 7,500 test cars pass along it annually.

At the other end of the proving ground is a low-friction surface road that is used predominantly to test ABS and adverse-weather performance. Again, split into multiple surface types as diverse as epoxy resin and pebbled road, the system operates in conjunction with a multiple nozzle sprinkler system to simulate varying levels of saturation and icy conditions.

In addition to this, there is a large steering pad used for both handling development and tire function analysis. According to Hwang, the two brands, despite sharing numerous platforms and over 90% of suppliers, are developed according to two very different ways of thinking. While Hyundai seeks to offer a composed and comfortable ride in its models, Kia variants are developed to offer a sportier feel with a focus on "being fun to drive".

Encircling all this is a 4.5km, four-lane, banked oval that allows speeds of up to 250km/h to be achieved. The two main straights are connected by the 43.5° banked corners, which aim to minimize centrifugal forces when cornering at speed, and allow test engineers to drive hands-off at high speed.

Complementing the proving ground is the Functionality Test department of Namyang, which houses a custom chassis dynamometer within an anechoic room. The NVH-tailored machine focuses predominantly on reducing vehicle body and component vibrations, and noise transference through the chassis and components. This is paired with a modal test room to further analyze the effects of tire friction noise, as well as the noises generated under braking and running at speed.

Namyang's facilities were central to the development and patenting of Hyundai-Kia's take on four-wheel steering. Active Geometry Control Suspension controls the inboard suspension link mounting positions, allowing a movement of up to 3° in toe-in/toe-out of the outer rear wheel, to confer the optimal geometry characteristic at any given point during heavy cornering.

• *Behind the wheel, page 60*

Built to last

BRIAN LABAN EXPLORES THE CHASSIS OF AN LMP2 SPORTSCAR, WHERE DURABILITY, SERVICEABILITY AND DRIVEABILITY ARE THE KEYS TO A SUCCESSFUL DESIGN

SPECIFICATIONS
Zytek Z11SN LMP2
Chassis: Carbon-fiber composite monocoque to FIA regulations
Suspension: Double-wishbone pushrod, front and rear
Brakes: Hitco 380mm floating, ventilated carbon-fiber discs with six-pot AP Racing calipers
Wheelbase: 2,820mm
Overall track: 2,000mm F/R
Weight: 900kg
Engine: Nismo VK45DE, 4,494cc, 90° V8. Four overhead camshafts. Zytek EMS 4.5.2 management; coil-over-plug ignition, with NGK plugs. Max. power 450bhp; torque 580Nm
Transmission: Ricardo. Transversely mounted; 6 speeds plus reverse

MAIN: **IN THE HANDS OF SIMON DOLAN, OLIVER TURVEY AND LUCAS LUHR, THE JOTA SPORT ZYTEK Z11SN-NISSAN FINISHED 10TH OVERALL, THIRD IN LMP2 IN THE 2013 6 HOURS OF SPA-FRANCORCHAMPS WEC RACE**

There were 30 prototypes at Le Mans in June 2013; 22 were LMP2s, a high proportion having a real chance of at least a podium – a far cry from the days, not so long ago, when you could count the 'second division' on one hand, and when mechanical fragility meant finding enough survivors even to fill three steps wasn't a given.

LMP1 is dominated by manufacturer budgets. LMP2 is cost-capped, both for purchase and servicing, with sensible restrictions on 'exotic' materials and technologies, which as well as making the cars affordable, means they can be run hard but reliably, with decent life expectancy. So finally, LMP2 is what it was always meant to be – a strong customer category in its own right, fiercely contested between a good number of serious teams, supported by a healthy family of chassis and engine suppliers, with others watching closely.

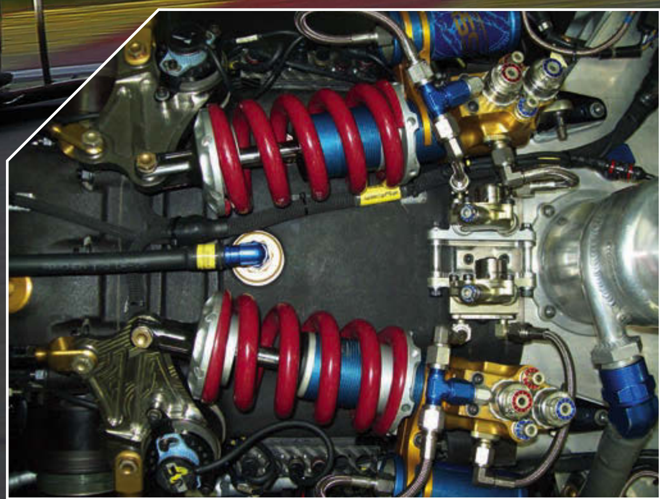
Zytek is at the sharp end of LMP2 as both a chassis and (Nissan) engine supplier. Tim Holloway has underpinned Zytek's success. With Trevor Foster, he set up Zytek's chassis division alongside its established engine division, as chief designer. Officially, he retired from Zytek almost three years ago, but still helps with various projects. He's also technical director for Jota Sport, which was Zytek's first chassis customer (in 2004), and has continued to race with Zytek at Le Mans and in other ACO series.

Jota's 2013 Zytek was the Z11SN-Nissan, a potential Le Mans LMP2 winner before a suspension breakage dropped it to eighth, a regular front-runner in the FIA World Endurance Championship, and a perfect illustration of the current state of the LMP2 art.

"Within LMP2 materials limitations, the tub follows normal carbon-composite practice, designed by Zytek and fabricated in partnership with URT," Holloway explains. "Its footprint is essentially defined by (regulated) wheelbase, tracks, and wheel and tire sizes. There's scope to vary weight distribution, but a customer car potentially means different engines, implying different fuel, cooling and electronic systems – while

LMP2'S FUTURE

Tim Holloway is a staunch supporter of LMP2's cost-capping and rule stability, with current technical regulations essentially set until 2015. As such, he accepts that the past five years have seen more evolution than revolution in LMP2, and that the possibility of creating a dual-purpose chassis (while both technically and commercially enticing) is made increasingly remote by 2014 Le Mans regulations that say any LMP1 car must be a closed car, while LMP2 can be closed or (Holloway's own preference) open. "Even so," he says, "today's Zytek chassis is completely different from any of its predecessors, with no parts in common."



avoiding undesirable duplication or redundancy."

Many of those are now controlled by safety regulations, and the current chassis was the first Zytek ever to undergo (and pass) P1 crash tests, following simulations by Penso. "We had done squeeze tests and roll-hoop tests, and finally had to do impact tests, which was new in sportscar terms. Soon, sportscars will also have to do side-impact tests."

The fully load-bearing Nismo VK45DE 4.5-liter V8 bolts to the tub with four fixings, plus eight to bellhousing and oil-tank, ahead of a transverse 6-speed Ricardo gearbox with Zytek's electronic shift.

Both suspensions are pushrod, "because it's difficult to get an efficient pullrod system that's also easy to work on," Holloway explains. The layout is double-wishbone, with spherical joints at both ends, while spring, damper, anti-roll bar rates and ride heights are all fully adjustable. "And all links are steel, because we're not allowed composite ones in LMP2.

"Again that's about durability," he expands. "You build a car to withstand 24 hours of bouncing over curbs, and if you could afford to replace composite components as a service item, that would be fine, but you're also building to a running-cost budget."

Ride height variations are crucial in optimizing setup, and central bump-stop adjusters on the front and rear suspensions control that independently of damper settings. T-shaped front and rear anti-roll bars are pitlane-adjustable, but onboard driver adjustments are illegal; similarly, camber and toe settings are adjustable, while variations in anti-dive and anti-squat are limited by regulations that permit only a 5mm change from nominal design positions.

The Jota Z11SN uses six-way-adjustable Dynamic Suspensions dampers, adjustable for high- and low-speed bump and rebound, with vertical blow-off for curb strikes, and *g*-sensing under braking – which gives a massive choice in creating setups to suit all conditions, but relies heavily on the experience of the engineers and team.

Precise setup figures are confidential, but ball-park camber settings range from -1.75 to -3.5°

INSET: **REAR SPRING-DAMPER SETUP FEATURING DSSV DAMPERS AND EIBACH SPRINGS. PUSHROD CONFIGURATION IS EASY TO WORK ON**

ABOVE: **FRONT BRAKE DETAIL SHOWS FLOATING CARBON-FIBER DISC WITH AP RADI-CAL SIX-PISTON CALIPERS**

ONE SIZE FITS ALL

The new Dunlop front tire for 2013 had quite different vertical stiffness to before, and was seen by the Jota team as a step forward, but the optimum setup involved quite different settings to those used previously.

"Even with several different chassis and a lot of different teams, what's interesting is that a good tire will usually work for everybody," says Tim Holloway. "If the tire maker has to go off on a tangent to make a tire that works for a particular chassis, it's usually because the chassis isn't very good."

CLOCKWISE FROM ABOVE: **DOUBLE-WISHBONE REAR SUSPENSION; THE TEAM BELIEVES THAT ITS ZYTEK IS THE EASIEST OF ALL THE LMP2s ON ITS TIRES; THIRD SPRING ON THE FRONT SUSPENSION CONTROLS THE RAKE OF THE CAR AT HIGH SPEED**

front, and -1.25 to -2.5° rear, depending on circuit; low-downforce Le Mans is very different to Imola, for example. Similarly, toe settings change from track to track, within a range from 4mm in to 4mm out. And castor can be fixed at a very high figure because the Z11SN's rack and pinion steering has electronic assistance (by Japanese company Kayaba) to overcome the extra steering weight. The driver can also select a preferred steering weight to suit grip levels at any particular time, from six settings, which can be pre-programmed by the manufacturer. Wheel rate ranges from 900 to 1,800lb/in front and rear are again dependent on track and conditions.

"We do suspension load tests, torsion-tests, and then use the [Multimatic] four-post rig at Thetford to develop whole-car dynamics," says Holloway. "But each driver also has to be comfortable with the setup. We have to give them a bit of slack. One might say the balance is perfect, one says 'understeer everywhere', the third says 'it's a bit nervous'! It's actually about the drivers, not the car, and it's usually the best driver who says it's perfect – but he's the one who often has to sacrifice optimum lap time for driveability for the others. In design, we have the same compromise: rather than build a car that might be peaky and super-quick over one lap, we need one that's easy to drive over 30 laps. So you do sacrifice ultimate performance for driveability."

In-race serviceability is a key element in brake layout. "It's interesting how endurance-racing brakes have developed," he remarks. "Six-pot AP Racing calipers with floating carbon-fiber discs (made by Hitco and supplied through AP Racing) would have been considered high-end F1 spec a few years ago, but show how close customer sportscar materials technology has moved to F1 standards."

Front and rear cooling ducts allow the option to cool calipers and discs independently, depending on circuit and conditions – Imola, for example, demands maximum cooling whereas Le Mans is very easy on brakes, as high speeds and long straights inherently cool them well. The driver also has a front-to-rear brake-balance adjustment control to optimize braking effort on all four wheels.

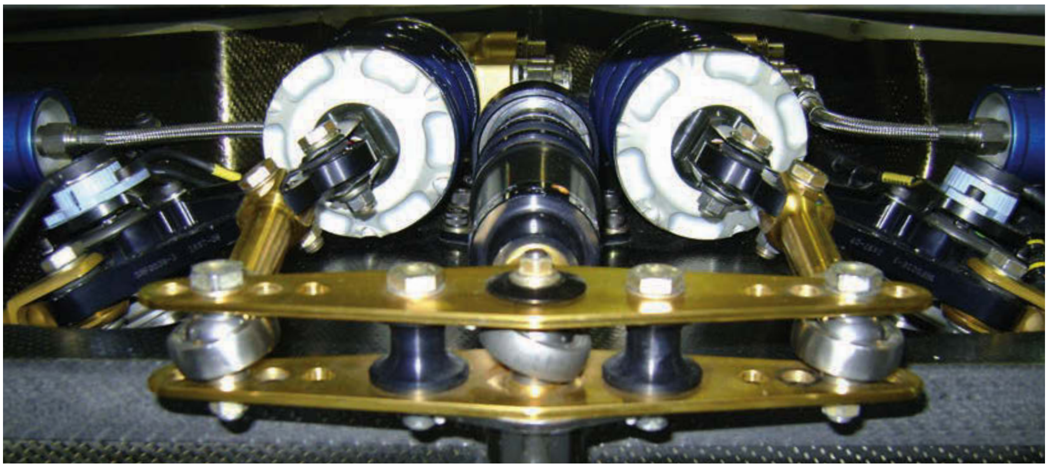
"Cooling is less of an issue than it might seem; you know how much you need from the engine data, so it's the packaging that's important. The more efficient you can make the ducting, the smaller you can make the radiator surfaces."

Durability does mean weight is an issue, however. "When LMP2 started, as LMP675, getting to 675kg was very demanding," Holloway recalls. "Even at 700kg the car wasn't very reliable, so we had to beef things up and weight went up as the regulations evolved, to 800kg, and now, in reality, 900kg – although carrying a fair amount of ballast helps with being able to balance the car."

The car's aerodynamics suffer complexities unique to endurance racing – big variations in circuit type, high speed-differentials and very different wake patterns from prototypes and GT-class cars. But Le Mans dominates everything. "Going back a while we chased maximum downforce, reasoning that it would be difficult to win Le Mans with a P2 car, but given maximum downforce a customer team could win six-hour races. That proved correct. Now, we pursue minimum drag but push toward high-downforce configurations. At Le Mans we can take downforce off to reduce drag and be as competitive as possible."

But there's another side to this equation. "Having as much downforce as possible makes a car easier to drive – at Le Mans in particular," he continues. "In sportscars, you can be lucky if you're on the ideal line more than once or twice a lap, which makes aero flexibility even more important. Making the car easier for a 'gentleman' driver over a three-hour stint means less chance of him making a mistake. A driver-friendly car means less curb abuse, fewer crashes. Repairing damage kills private teams for both time and resources. Once you get on the back foot, you tend to stay on the back foot. A customer car has to be more than fast; it has to be user-friendly for the driver, and pit-lane friendly for the team."

That said, aero changes are also limited by regulations. There are two adjustable (diveplane) elements on the front and a fully adjustable two-piece rear wing. Ride heights have a big effect on aero balance but are ultimately limited by having to run a regulation plank under the car that has to stay within a range from 25mm new to 20mm fully worn. For Le Mans, a one-off aero package is permitted, because speeds of over 300km/h contrast starkly with, say, 265km/h at Silverstone.



Hollow triumph

THE TR7 AND ITS TR8 DERIVATIVE WERE THE LAST OF THE TRIUMPH SPORTS CARS. **GRAHAM HEEPS** LOOKS BACK AT A CAR WHOSE APPALLING QUALITY WAS LEGENDARY

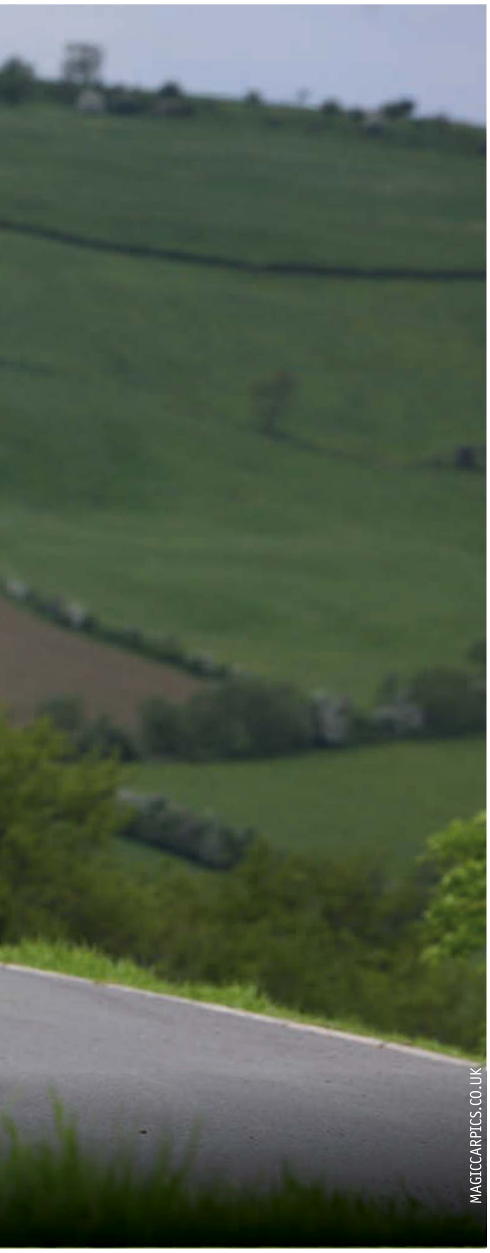
Triumph's Roadster (TR) sports cars had been popular since the 1950s with dashing young men and weekend racers on both sides of the Atlantic. Particularly in North America, sales had remained strong into the early 1970s, by which time the beefy, straight-six-powered TR6 – a Karmann reskin of the Michelotti-designed TR4/5 – was bringing in valuable export dollars for the troubled British Leyland Motor Corporation (BL).

Triumph had been part of the all-encompassing BL conglomerate since 1968. A deteriorating financial position and internal politics within the corporation – including between factions representing the former BMC interests (including Austin, Morris and MG) and erstwhile Rover/Triumph business – led to a series of false starts and lengthy delays in the development of a successor to the aging TR6. When it did finally go on sale in the US market in early 1975, it suffered from abysmal build quality, endowing it with a poor reputation from which, in sales terms, it would fail to recover.

Chassis-wise, the TR7 was far less radical than its controversial 'wedge' styling would suggest. The initial hardtop design was conceived against TR tradition in the belief that the National Highway Traffic Safety Administration's (NHTSA) proposed FMVSS 208 legislation would make convertible cars unsalable in the USA, although, after a courtroom challenge, this never became the case.

The TR7's style hinted at a mid-engine design, but it was a conventional front-engine, RWD machine. The front suspension was by MacPherson struts; at the rear the TR7 had the simple live-axle suspension that was typical at the time.

"The rear axle was located by four links – two longitudinal lower arms and two upper arms angled in plan view, inward from the body to attachment points close to the differential housing," explains Clive Roberts, who had joined Triumph as a student apprentice in 1971 (see *Eyewitness*, overleaf). "That provided the lateral location, albeit within the context of the tires, expectations and knowledge of the time. The base 2-liter TR7 had an adapted 4-speed gearbox from the Morris Marina and used a wider version of the Marina rear axle. The four-valve 'Sprint' model [which reached the preproduction stage but never went



on sale] would have used versions of the Rover SD1 gearbox and rear axle (without the Watts link), but their additional mass defeated the purpose of the more powerful engine, which is one reason why it never appeared."

Another was that in an era of turbulent relations between unions and management, and continual strikes at UK car plants, Triumph's troublesome Speke factory in Liverpool was closed for good in early 1978. With that, TR7 production was transferred to the marque's traditional home in the Canley district of Coventry, but astonishingly, would move again – in 1980, to the Rover factory in Solihull – before the end of the car's six-year life. At a time when running BL was an exercise in crisis management, it seems that the Sprint's lack of a clear performance benefit – on paper at least – made it an easy target for managers looking for 'safe' product choices.

A notable feature of early TR7s was the high rear ride height. It is known that generous wheel travel had been requested by the then Triumph engineering director and former Rover man, Charles Spencer 'Spen' King (succeeded from 1974 by John Lloyd, who was already overseeing operations day-to-day). The resulting tail-up attitude of early production cars – with daylight from the far side of the car visible above the rear tire – may have been a consequence of the kinematics resulting from long wheel travel on a live axle. In David Knowles' comprehensive book *Triumph TR7 – The Untold Story*, it is explained how this was initially fixed cosmetically by a shield to blank off the gap; a 1977 revision subsequently lowered the rear suspension by 25mm (1in).

The TR7's ride and handling was developed in the pre-rig and pre-simulation era. According to Roberts, the work was led by engineers Brian Howe and Gordon Birtwhistle: "As far as I remember development was entirely subjective, guided by basic load transfer distribution calculations," he recalls. "I was delighted to act as human ballast for ride evaluations on the lanes around Canley!"

Along with other aspects of the car's development, it's likely that handling work was conducted at MIRA, since there were few alternatives in the UK in the early 1970s. It's known that the development team also frequented the Welsh roads around Bwlch-y-groes for endurance testing.

Contemporary road tests were generally complimentary about the TR7's handling balance, but in the face of the ongoing quality issues and divisive styling, this was not enough to lead to the hoped-for sales performance. Even its creators appeared to lack enthusiasm for the car – perhaps a reflection of the politically charged environment of the time: "Even as an awestruck student, amazed to have stumbled into a job in the most exciting place on Earth, I just couldn't get

LEFT: **POP-UP HEADLIGHTS WERE A DISTINCTIVE – AND INITIALLY TROUBLESOME – TR7 FEATURE**

ABOVE: **THE UNMISTAKABLE WEDGE PROFILE IS EVIDENT ON THIS 1978 SPEKE-BUILT TR7**

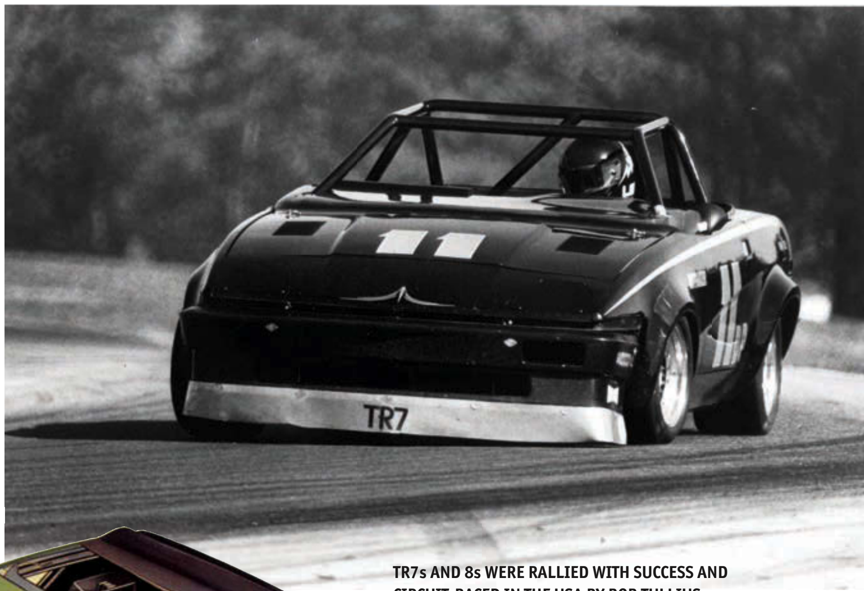
TOP: **1975 PUBLICITY SHOT OF A FIXED-HEAD TR7, PROBABLY TAKEN ON THE MIRA BANKING**

SPECIFICATIONS
Triumph TR7
Dimensions: 4,064mm (L) x 1,575mm (W) x 1,270mm (H, coupe). Wheelbase 2,159mm
Weight: 1,071kg (coupe), 1,067kg (convertible)
Engine: 105bhp (Europe) or 92bhp (North America) 1,998cc, eight-valve I4
Suspension: Front MacPherson struts with lower single link. Spring rate 15.4N/mm (TR8: 16.5N/mm). Rear four-link system with coil springs; spring rate 29N/mm. Front and rear ARBs
Brakes: Disc brakes at the front and drums at the rear
Steering: 3.88 turns lock to lock
Wheels/tires: Steel wheels with 175/70 HR13 tires, later widened to 185/70 HR13s

enthusiastic about the TR7," says Roberts. "That was a common feeling around the [Canley] building – people who spent their evenings and weekends building and racing interesting cars based on the Triumphs of the day (GT6, TR6, etc) looked on the TR7 as a dull and ugly thing.

"The convertible almost retrieved it," he continues. "There was a definite buzz around the workshop when they first cut the roof off a coupe. Likewise for the proposed Lynx 2+2 – we believed in that and wanted to make it work, but there was probably no stopping the downward slide by that point."

Unlike the Lynx, the TR7 convertible finally made production



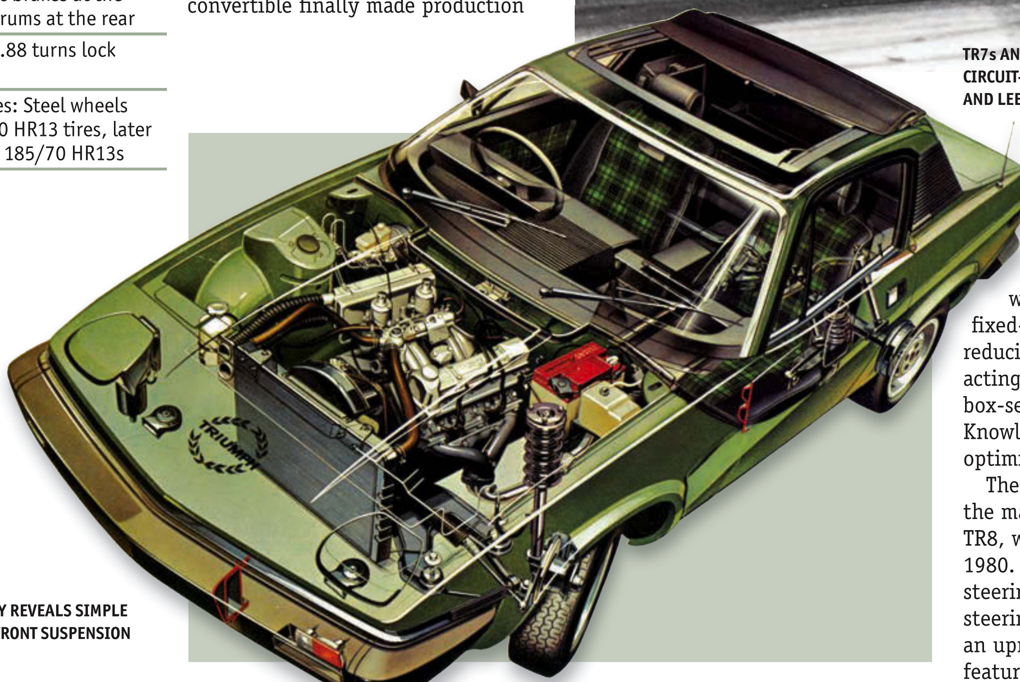
TR7s AND 8s WERE RALLIED WITH SUCCESS AND CIRCUIT-RACED IN THE USA BY BOB TULLIUS AND LEE MUELLER (ABOVE), AMONG OTHERS

in 1979, more than three years after Lloyd's team first decapitated a coupe. Another prolonged gestation was hampered once more by the move to Canley. The chassis was largely unchanged from the fixed-head car, save for two shake-reducing additions: a front bumper acting as a tuned absorber and a box-section behind the front seats. Knowles relates how the latter was optimized with early FEA software.

The other TR7 derivative to reach the market was the Rover V8-engined TR8, which was sold in the USA from 1980. This car received an Adwest steering rack that sharpened the steering to 2.8 turns lock to lock, an uprated brake package that featured 9.7in front discs and 9in rear drums, and standard 13in x 5.5J alloy wheels.

The TR8 offered the more macho successor to the TR6 that some buyers had wanted all along. By this time, too, many of the early quality issues with the TR7 had been ironed out and BL's factory output was no longer crippled by continual strikes. But the more stable industrial and political climate under Thatcher's government led to a rise in the value of the pound, which made it harder to sell the improved cars in the USA, their main market, at a competitive price. This ironic turn of events contributed to the ending of TR7 and TR8 production in October 1981.

Recommended reading:
Triumph TR7 – The Untold Story, by David Knowles



RIGHT: **CUTAWAY REVEALS SIMPLE MACPHERSON FRONT SUSPENSION**

ABOVE: **THREE TR7s WERE TRIMMED WITH LEVI DENIM AND PAINTED IN A BESPOKE COCA-COLA SCHEME AS PRIZES FOR A 1978 COMPETITION**

EYEWITNESS

"I joined Triumph on a five-year sandwich course linked to a mechanical engineering degree course at Lanchester Polytechnic (now Coventry University)," explains Clive Roberts, the current director of vehicle integration at SAIC Motor Corp. "I worked in many parts of the Canley plant, but was increasingly based in the Engineering Building. As I approached graduation, I spent more time under John Falloon in the technical office, which was where the 12 graduate engineers manipulated their slide rules to keep the vast drawing office supplied with stress and sizing calculations. My first job was to check the stresses on a detent spring in the '77mm' gearbox destined for the Rover SD1 and TR8.

"This group also contained specialist tire and brake engineers who worked with the test engineers and test drivers in the development office, led by Tony Lee. On graduating I worked for Dave Wright in the vehicle safety section, but inclined toward brakes and dynamics work until I moved to Caterham Cars in 1978.

"The political situation within BL at the time was sad and bewildering – I just wanted to work with cars! One day I was outside the office of engineering director John Lloyd as he walked out, calling to his secretary, 'I'm going to lunch. If my new boss calls, take his name!'"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Steering-in-the-loop

FIGURE 1: **SIMULATION OF AN INDIVIDUAL TRAFFIC SCENARIO AND STEERING SYSTEM TEST BENCH** (INSET)

The integration of an electromechanical steering system into the whole vehicle poses major challenges to engineers in the development process. The steering system is part of complex interlinked networks of mechatronic systems in the vehicle. There is a wide range of interdependencies and action chains that influence both handling and fuel consumption. Therefore, integration and interlinking at the level of the whole vehicle has to take place in the initial stage of the development. At later stages in the process, faults in the action chain result in high additional costs. This leads to the following questions: how can steering feel be evaluated in the virtual and/or partially virtual world? And how can driver assistance functions be validated?

These questions can be answered only by examining the whole vehicle in realistic driving situations. An isolated look at individual domains does not resolve these issues. This is the point at which the X-in-the-loop approach sets in. X-in-the-loop (XIL) stands for the consistent and seamless inclusion of all components and systems – whether as models, software or hardware – in the whole vehicle. As a result, a virtual prototype is created, which can be comprehensively tested using the tools and methods of virtual test driving at any development stage based on identical driving maneuver catalogs and evaluation criteria, which come from real-world testing and final validation. This integrated view of the whole vehicle allows the development engineer to determine at any point in time how the steering system, in conjunction with all other systems, affects the vehicle's handling properties (Figure 2).

Test platform and steering system test bench

A detailed simulation of vehicle physics and the vehicle's environment, such as the CarMaker open integration and test platform, is the prerequisite for using the XIL approach. CarMaker provides an interface architecture that is attuned to the vehicle development project. Models, software and physical vehicle components can be integrated into the virtual vehicle environment by mouse click and different test bench configurations are used according to the stage of the development project.

In steering-in-the-loop tests, the complete steering system, consisting of the steering wheel, steering column, steering gear and ECU, is set up on a hardware-in-the-loop (HIL)-capable steering system test bench and tested in a virtual prototype. The innovative steering system test bench of Munich University of Applied Sciences is an example. The simulation of the whole vehicle environment and test automation are based on CarMaker.

On the hardware side, the steering system test bench reflects the installation of the steering system in the vehicle. The steering rack forces are generated by two linear motors to the left and right of the rack. These actuators generate the forces that are calculated in the simulation by CarMaker, and simultaneously measure the current position and force applied at the rack.

The steering wheel is linked to a steering wheel motor that carries out the driver's input and, depending on the application, is controlled by the steering wheel angle (steer-by-angle) or the steering wheel torque (steer-by-torque). In the steer-by-torque mode, the steering wheel torque is calculated by the driver model IPGDriver and applied by the steering wheel motor. This steering wheel torque produces tie-rod force changes, caused by a shift of the rack, which are fed back into the simulation.

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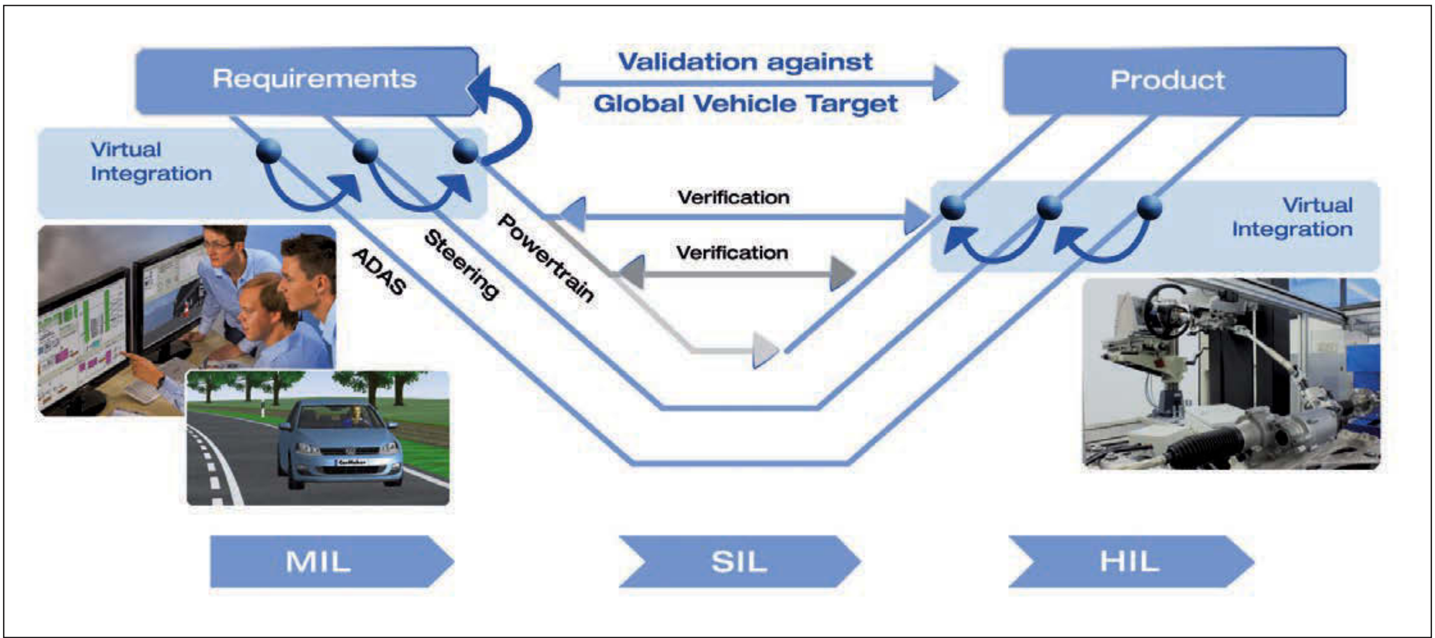


FIGURE 2: **SEAMLESS X-IN-THE-LOOP APPROACH**

Maneuver and criteria catalog

In addition to the driver, vehicle and environment models, the test platform offers a maneuver description, which is based on the principles of real-world road testing. Closed-loop and open-loop maneuvers are described by a sequence of maneuver instructions derived from physical road testing. Therefore, the 'same language' is spoken on the test track, on the HIL test rig and in offline simulation.

This consistency makes it possible to work with an identical maneuver catalog and identical evaluation criteria across all the development stages. The creation of such a catalog requires a high level of expert knowledge, particularly in the case of steering system developments. Steering/road feel and steering behavior heavily depend on the subjective experience of individual drivers. Consequently, the subjective evaluation plays an important part in the development and calibration process.

Subjective evaluation criteria include, for example, initial steering response, on-center steering feel or straight-line running behavior. Therefore, the derivation of driving maneuvers and measurable quantities for these subjective criteria is a key step. The weave test according to ISO 13674-1, for instance, provides conclusive characteristics for evaluating on-center steering feel. These characteristics are primarily determined from the lateral acceleration and the yaw velocity as well as the steering wheel torque and the steering wheel angle. Other important maneuvers for objective evaluation of steering behavior include the slowly increasing steer (SIS) test, step steering input and single sine. But the testing program of a modern steering system also includes closed-loop maneuvers such as lane change and µ-split braking, as well as extended test driving, for instance on rough roads.

The test catalog that has been developed can be used in any XIL domain, i.e. in simulation (offline), in the physical vehicle, on the ECU HIL or on the steering system test bench. Administration of the maneuver catalog in CarMaker's TestManager is carried out with ease and transparency. All model and maneuver parameters are accessible, allowing the fully automated performance of comprehensive parameter studies (Figure 3).

Optimization of steering ECUs

This maneuver-based approach has already been successfully used in a pilot project. Initially, a real-world test was performed on a test track to identify the strengths and weaknesses of steering behavior, which mainly concerned on-center steering response and straight-line running stability. The test drivers gave very positive ratings to the steering effort required while driving and parking. Based on this subjective evaluation, target values for the optimization of the ECU on the steering system test bench were defined. A subsequent sensitivity analysis showed the influence of the individual ECU parameters on the target values. As a result, it was possible to systematically improve the ECU parameters in direct interaction with the physical steering system (Figure 4).

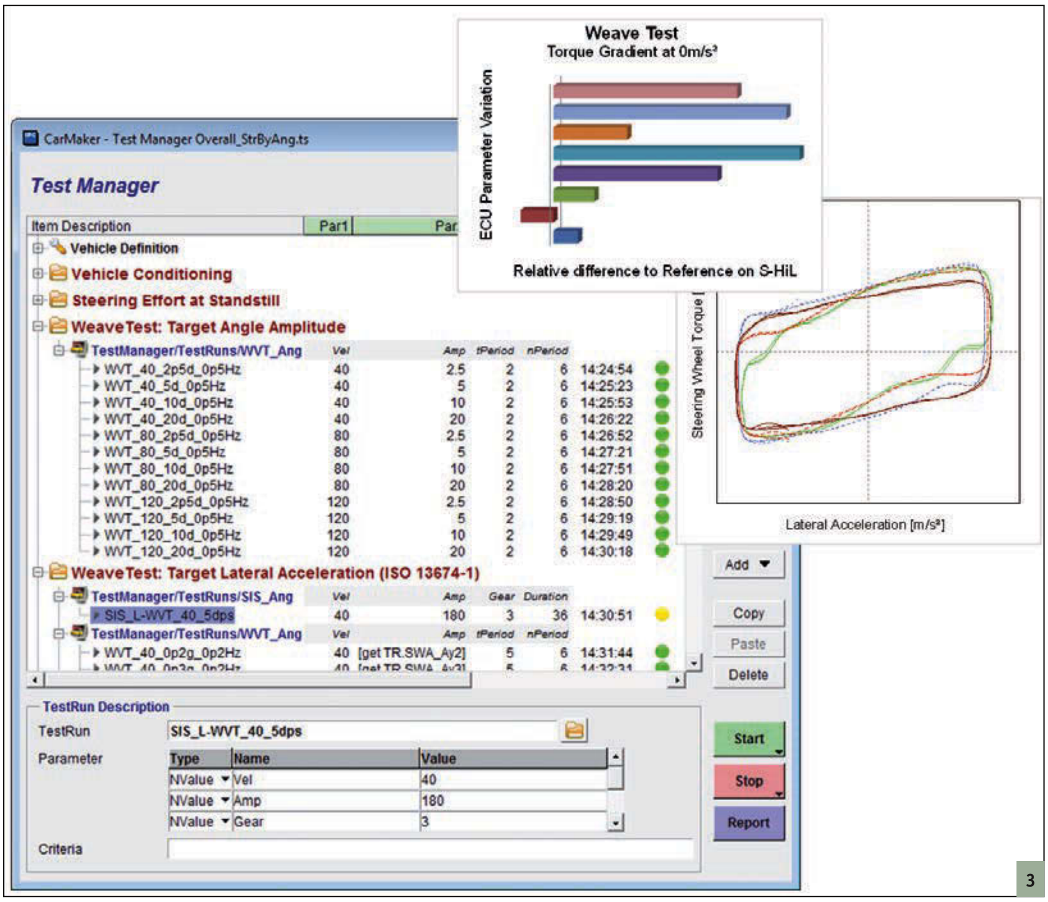
To test the acceptance of the new parameterization prior to integrating the ECU in the physical vehicle, the steering system test bench was converted into a driving simulator. For this purpose the steering wheel motor was disconnected from the steering system. Longitudinal dynamics (brake, clutch, throttle) were controlled by the driver model

IPGDriver while the test engineer steered. Even inexperienced drivers were able to feel the differences of the ECU parameters and to confirm an improvement in steering behavior on this driving simulator.

The final validation of the results took place in real-world road tests. Now the test drivers, across the board, positively assessed straight-line running stability and on-center steering response. The good ratings awarded for the steering wheel torque required at rest and the holding force while driving could be retained at nearly the same levels despite the ECU modifications. This shows that a very good basic calibration of the ECU can be achieved by means of the steering-in-the-loop method. The tuning and testing requirements during road tests are therefore reduced.

ADAS development

The development of driver assistance functions, such as parking assistance or lane-keeping assistance, is another field of application for the steering-in-the-loop method. For this purpose, CarMaker offers a comprehensive simulation environment. The traffic



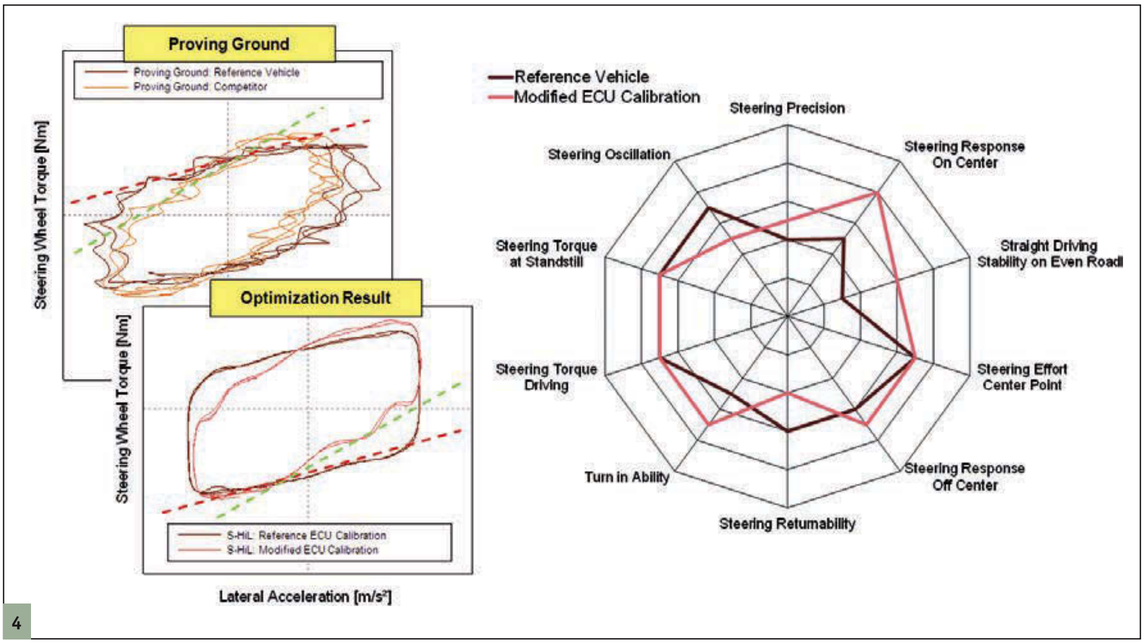


FIGURE 3: **MANEUVER CATALOG IN CARMAKER AND OBJECTIVE CRITERIA EVALUATION**

FIGURE 4: **VEHICLE MEASUREMENT AND RESULT OF STEERING SYSTEM TEST BENCH** (LEFT) **WITH FINAL SUBJECTIVE ASSESSMENT** (RIGHT)

FIGURE 5: **SIMULATION OF AN INDIVIDUAL TRAFFIC SCENARIO**

module IPGTraffic makes it possible to configure individual test scenarios with vehicles, pedestrians, parked cars, traffic signs, traffic lights and buildings (Figures 1 and 5).

For instance, to validate the lane-keeping function, trips on multilane roads with different layouts and markings are reconstructed. An important driving maneuver is the sine sweep all the way to the edge of the lane. If the vehicle departs from its lane, the driver assistance system helps, returning it to the center of the lane through a gentle steering wheel torque intervention. This presupposes that the assistance system can override the virtual driver in lateral dynamics.

In addition to the simulation of traffic scenarios, the CarMaker test platform offers models for all conventionally used sensors such as radar, lidar and ultrasound. For camera-based systems such as lane-keeping assistance, VideoDataStream is additionally available. This virtual camera model is embedded in the 3D real-time animation IPGMovie and has the capability to generate video data – place- and time-synchronized to the simulation – as grayscale, color or stereo images, as well as stereoscopic depth-of-field maps. As a result, image-processing algorithms can be incorporated into the simulation and validated either as a model or software, depending on the state of the development.

If, in the case of camera-based systems, the ECU is integrated into the test rig environment of the steering system as hardware, the challenge lies in transmitting the video signals to the ECU synchronous to the simulation. In earlier applications the original camera would film the animation of the simulation for this purpose. This lack of synchronization between the display and the camera posed a particular problem, however.

CarMaker has resolved this issue by using the newly developed VideoInterfaceBox to transmit the signals. The VideoInterfaceBox divides the input video signals of IPGMovie into separate video signals and transforms them so that, for example, they correspond to the camera images of the front and rear as well as the left-hand and right-hand side of the vehicle. All camera signals generated this way are synchronized in real time and can therefore be directly transmitted to the ECU. This makes sensor data fusion with the signals of other sensors and cameras possible as well. Consequently, the physical ECU and the physical steering system can be tested in the context of the whole vehicle and the steering and driver assistance functions can be coordinated with each other.

Conclusion

The steering-in-the-loop method presented here makes an efficient and comprehensive evaluation of steering behavior and steering system functions possible before real-world road testing commences. The open and modular structure of the CarMaker integration and test platform offers a wide range of applications combined with the reusability of tests and evaluation criteria, as well as reproducible results.

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Intelligent steering

RIGHT: **TEDRIVE HAS FURTHER DEVELOPED ITS PATENTED IHSA TECHNOLOGY AND ADAPTED IT FOR RECIRCULATING-BALL STEERING SYSTEMS FOR USE IN HEAVY COMMERCIAL VEHICLES AND BUSES**

The automotive industry is driven by three strategic safety targets: saving lives, mitigating environmental influences, and enhancing capabilities. Electric power steering (EPS) systems work in favor of these goals because they can offer intelligent safety functions that save lives. Also, the removal of bulky hydraulics benefits fuel economy, while the electric power assistance from the motor reduces the physical effort required to steer the vehicle.

However, these systems are restricted mainly to passenger cars. Larger cars and light commercial vehicles (LCVs) typically have either hydraulic or electrohydraulic steering, because of their weight characteristics. Value-added functions have traditionally been the exclusive preserve of electric power steering systems. But thanks to iHSA (intelligent hydraulic steering assist) technology from tedrive, the hydraulic steering assist system is able to provide comfort and safety functions previously delivered only in lighter vehicle segments by EPS, for all vehicle classes.

iHSA is a CO_2-optimized hydraulic steering system that enables the integration of various active features such as active lane keeping, crosswind compensation, trailer stabilization, park-assist, joystick maneuvering, and so on, into hydraulic steering systems for all vehicle classes, including heavy commercial vehicles and buses.

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, and simultaneously achieving CO_2 savings. For this purpose, reliable technologies were applied in the form of an activated rotary valve and a steering gear with a tedrive steel housing design, all based on proven manufacturing processes. In addition, the iHSA technology can be integrated using plug-and-play into recirculating-ball steering gears for trucks and buses as well.

The main engineering objective was to be able to provide comfort and safety functions in all vehicle classes, especially in SUVs, LCVs, trucks and buses. In these segments in particular, but also in all other vehicle classes, professional drivers could benefit from the support provided by driver assistance systems.

iHSA offers the best of both EPS systems and traditional hydraulic steering systems (HPAS/EHPS), while also being robust enough for installations on light commercial and commercial vehicles or buses with high front-axle loads. Apart from its exceptional technological advantages, the iHSA solution requires original equipment manufacturers to spend less per function, which can be a deal clincher in a highly cost-sensitive segment.

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

TOP: **THE OPTIONAL USE OF IHSA TECHNOLOGY AS AN ADD-ON MODULE IN HYDRAULIC RACK-AND-PINION STEERING FACILITATES THE INCORPORATION OF ALL SAFETY AND COMFORT FUNCTIONS IN THE HEAVY VEHICLE CLASSES FOR THE FIRST TIME**

BELOW: **IHSA INTELLIGENT HYDRAULIC STEERING ASSIST IS A STEERING SYSTEM WITH THE FUNCTIONALITY OF AN ELECTROMECHANICAL SYSTEM. PICTURED LEFT IS THE IHSA MODULE FOR RACK-AND-PINION STEERING; RIGHT IS THE IHSA MODULE FOR RECIRCULATING-BALL STEERING GEARS**

steering systems can apply only limited rack forces, even with extensive manipulation of the onboard energy management system, whereas tedrive's iHSA is distinguished by its ability to exert much greater rack forces without having to make any changes to the energy management. In terms of functional safety, the iHSA system has been rated by TÜV Süd between ASIL B and C. For OEMs, this means considerable safety-related time and cost savings in comparison with EPS systems, which incur far higher development costs because of their ASIL D safety rating.

Designed to suit both rack-and-pinion type steering and recirculating-ball steering systems, the iHSA product range is characterized by great modularity that suits various platforms. It is independent of front-axle load and is packaging-optimized, which makes it highly suitable for installation on multiple vehicle models, regardless of their weight.

The passenger vehicle and commercial vehicle sectors are showing keen interest in the iHSA solution due to industry dynamics and the growing need to integrate safety solutions into steering systems. Being a plug-and-play solution, the OEM orders the iHSA system only if the end customer has requested the full range of steering functions.

tedrive is expanding outside its traditional European markets of Germany, Sweden and the UK, as well as the USA, and has gained considerable traction in markets such as Turkey, India, China, Argentina and Russia. This expansion has prepared the company for years to come, as emerging markets are likely to hold the maximum revenue potential in the near future.

OEMs from new markets are strengthening business ties with tedrive in considering torque overlay solutions such as iHSA for their vehicle model line-up. Invigorated by its current success, tedrive is also planning to introduce products based on EPS technology. In addition, tedrive is paying particular attention to lightweight steering solutions, which are expected to be an ongoing focus of OEMs in coming years.

AWARD WINNER

Every year, Frost & Sullivan presents the 'Europe Frost & Sullivan Award for Product Leadership' to the company that has demonstrated innovation in product features and functionality that provides enhanced quality and higher value to customers. In 2013, tedrive received this award for its iHSA system.

The award recognizes the rapid acceptance such innovation finds in the market. Frost & Sullivan's Best Practices Awards recognize companies in a variety of regional and global markets for demonstrating outstanding achievement and superior performance in areas such as leadership, technological innovation, customer service and strategic product development. Industry analysts compare market participants and measure performance through in-depth interviews, analysis, and secondary research to identify best practices in the industry.

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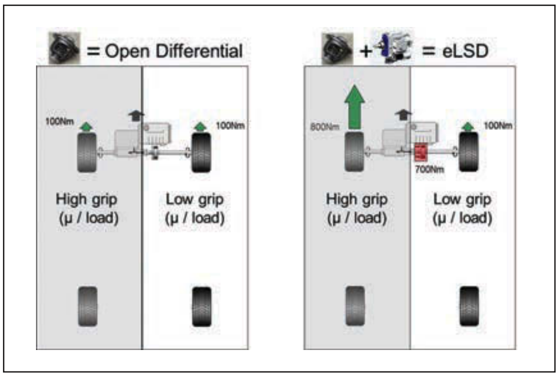
Quote ref VDI 002

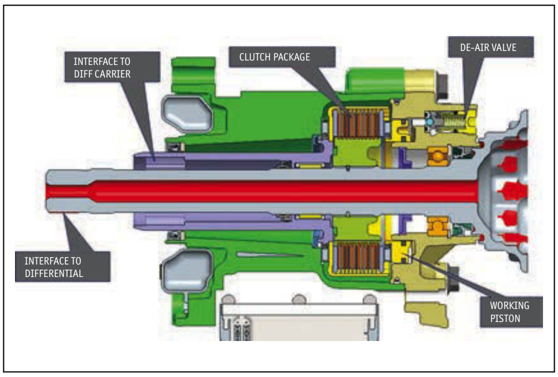
Torque transfer system

RIGHT: **COMPARISON BETWEEN BASIC PRINCIPLES OF OPEN DIFFERENTIAL AND ELECTRONICALLY CONTROLLED DIFFERENTIAL**

FAR RIGHT: **FXD MODULE CROSS-SECTION DETAILS**

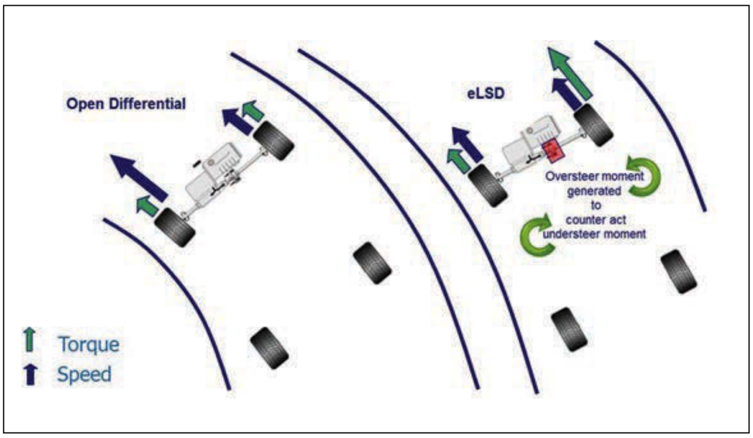
BELOW: **FWD FXD YAW GAIN FOR REDUCED UNDERSTEER**





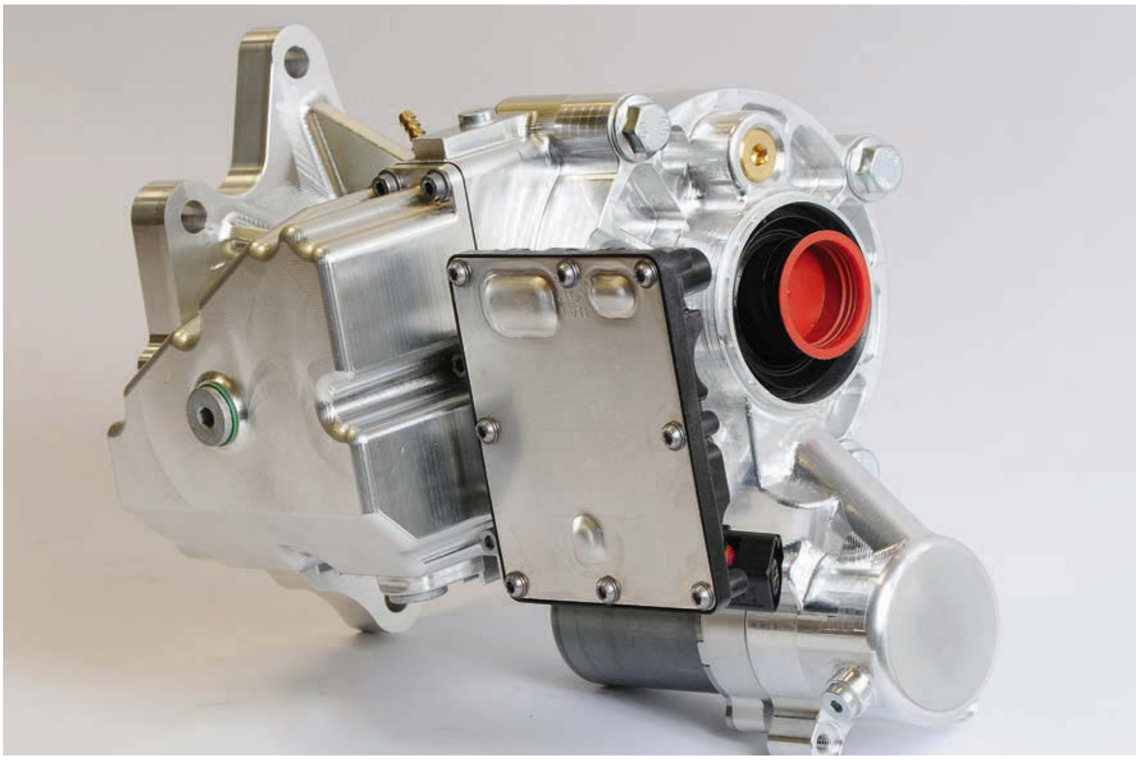
Open differentials allow equal torque distribution to the left and right wheels while the wheels rotate at different speeds. However, they are limited when one wheel touches slippery ground, such as ice or loose gravel, where its counterpart remains on a high-traction surface. Similar restrictions also manifest themselves in dynamic driving situations like cornering on level surfaces or off-camber turns as downforces on one of the driving wheels can be significantly reduced, resulting in decreased traction. Brake-based traction control systems are able to augment the shortcoming to a certain extent by applying the wheel brake on the wheel with high slip and low traction to generate a reactive torque. As they decrease engine power, brake-based traction control systems are still less than ideal.

BorgWarner's front-wheel-drive FXD module addresses the inherent boundaries of open differentials. A key advantage of the FXD system is its ability to preempt the driver's intentions for advanced traction performance. Based on sensor inputs regarding vehicle speed, steering wheel angle or rate of throttle applied, it efficiently directs the available driveline torque to the wheel with better traction by creating a locking torque between the wheels. This is accomplished by electronically controlling a hydraulic clutch in which the inner clutch plates are connected to one wheel, while the outer plates are attached to the case of the differential. By varying the hydraulic pressure, a controlled locking torque can be applied to both wheels. Compared to open differentials, with a brake-based traction control system, active FXD greatly improves the vehicle traction in terms of wheel slip and exit speed. In addition, vehicles with FXD require lower average driveline torque to climb hills than those with open differentials.



FWD vehicles furthermore inherently understeer when accelerating hard in a turn; this is considered a stable behavior as the reaction of most drivers is to lift-off on the throttle and the vehicle typically self-corrects. The outer wheel has the higher traction potential due to the higher downforces. However, the inner wheel is less loaded and begins to lose traction due to excessive wheel slip. The open differential is then limited on what can be provided to the outer wheel. The eLSD system provides an appropriate coupling torque through the clutch to send more torque to the outer wheel. This creates an oversteering moment that cancels the inherent understeering moment of the vehicle. The vehicle basically tracks the steering intention of the driver through the turn, resulting in enhanced cornering performance with minimal intrusion from brake-based traction and stability systems.

In power-off situations in a curve, the high slip angle of the front wheel, combined with a sudden dynamic weight shift, can create an undesirable oversteering reaction. Brake-based stability control systems do detect this situation and correct the vehicle's yaw tendency by applying certain wheel brakes to stabilize the vehicle. Depending on the vehicle, though, this approach tends to be a very abrupt and intrusive feeling from a driver's perspective, and therefore does not necessarily qualify for a fun-to-drive experience. The FXD couples the two



LEFT: **THE BORGWARNER FXD DELIVERS IMPROVED FWD TRACTION, HANDLING AND STABILITY**

wheels together, sending more torque to the inner wheel, which enables yaw damping, i.e. an understeering moment that cancels the prevailing oversteering tendencies of the vehicle. Immediately occurring, this stabilizing effect sets the vehicle into a stable state before the thresholds are exceeded on the brake-based stability system and results in driving behavior where a vehicle is much more fun-to-drive with less brake-based stability system interventions. Vehicles with active FXD are more stable when they recover from lane-change maneuvers and require less steering wheel input.

The FXD module consists of a standalone assembly comprising a clutch, a centrifugal electrohydraulic (CEH) actuator, an integral link shaft and an electronic control unit (ECU), and it bolts to the side of the transmission. Usually the output of the transmission requires minor modifications to enable a connection to the differential case and output seal. The alterations are not necessary if the transmission is already configured for an AWD power transfer unit. Then the FXD module can be directly mounted to the interface without further transmission modifications.

Producing the hydraulic pressure to provide the required torque transfer, the CEH actuator corresponds with the actuation system developed for BorgWarner's fifth generation of all-wheel drive couplings that launched in 2012. Several other core AWD coupling components have also been carried over to the FXD module, translating to economies-of-scale and commonality across different and proven product lines.

The CEH actuator integrates an axial piston pump driven by an electric motor with an innovative centrifugal overflow valve. The patented design allows for rapid pressure reduction as the pump speed is reduced. Moreover it offers direct control over the hydraulic pressure and features three centrifugal levers, each rotating around fixed attachment points and designed to guide ball valves to control the oil flow from corresponding pressure channels.

The CEH actuator permits the use of a brushed DC motor that does not require changes in its rotational direction. Variations of the current to the electric motor enable control of the motor torque that is directly proportional to the output hydraulic pressure applied to the working piston and subsequent compression of the clutch package. Oil flow is pumped constantly through the three half-open ball valves. With increasing motor speed, the valves are temporarily closed and the oil flow is directed behind the working piston, leading to pressure increase until a new steady state is achieved and the ball valves return to a half-open position. Correspondingly, a decrease in speed leads to a full opening of the ball valves and oil is evacuated from the working piston channels until the next steady state is achieved.

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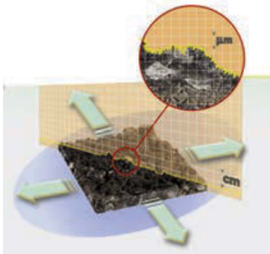
Testing and training

BELOW: **POLYDYAM HAS THE TOOLS TO CHARACTERIZE A TRACK'S SURFACE ROUGHNESS FOR VEHICLE OPTIMIZATION**

BOTTOM: **THE JRX TRAINING VEHICLE IN ACTION**



PolyDyam is a French company located in the center of France near Clermont-Ferrand. The company has expertise in the testing of rubber, polymer and elastomer parts, and materials, in the field of vehicle dynamics, aeronautics and future vehicles. It aims to offer a complementary and competitive range of services on a national and international scale in the field of mobility.

PolyDyam says it uses its knowledge in the science of materials and the behavior of vehicles with additional skills, to support customers from the start of an idea to the manufacture of a new product. This includes all steps from conception to simulation, prototype manufacturing, testing to engineering. To achieve this, PolyDyam can perform characterization bench tests for materials, components, subsets or global vehicles, and tests in real conditions on a track close to its headquarters.

While providing competitive analysis of a product or completing extensive R&D projects, PolyDyam can perform tests in the formulation and characterization of properties and behavior as well as failure analysis and lifetime prediction for elastomers, polymers, natural plastics and composite materials.

The company also has experience in other areas such as vehicle behavior analysis and is able to suggest suitable adjustments to make improvements.

PolyDyam has additional expertise in areas including measurement, tire and suspension analysis, vehicle dynamics, numerical modeling and simulation.

Central to this, PolyDyam says, is a physical testing approach adapted to the needs of the customer. A skid trailer can perform tire characterization (force and moment modeling or tire labeling). A track's surface roughness can also be characterized. Non-destructive testing of tire tread dispersion can be carried out on-site, and the development of a rolling chassis or hybrid vehicle adaptation is possible.

PolyDyam's experience extends to noise, vibration and harshness (NVH) testing.

The acoustic comfort of a car is linked to a reduction in the noise level induced by the powertrain; however, PolyDyam notes that this is not the only criterion to be taken into account. Both inside and outside noise are related to various aspects, not just the engine. Indeed, certain types of noise, even at low levels, can be perceived as unpleasant or tiring. Contrary to this, various different noises can

LEFT: **SKID TRAILER USED TO PERFORM TIRE CHARACTERIZATION**

POLYDYAM TRAINING VEHICLE

The Junior Rally Cross (JRX) was created in 2012. The marketing objective was to propose a design suitable for young drivers aged 14 to 18. However, the main objective is to provide a tool for young apprentice mechanics, technicians and engineers to train with for their future profession. As such, the JRX has been designed as a true racing car.

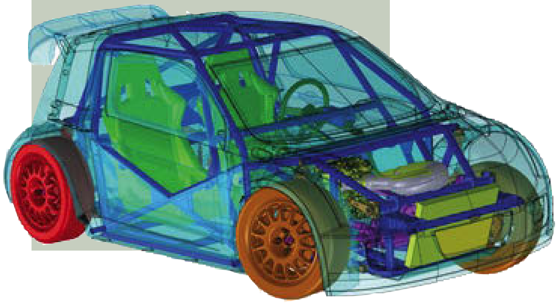
Engine: Two-cylinder, 600cc bi-turbo. 120bhp and 108Nm

Transmission: switchable 4WD with sequential 5-speed gearbox

Body: Composite tubular frame

Weight: 610kg

Datalogging: AIM data acquisition recording F/R brake pressure, steering angle, gear position, throttle opening, longitudinal and lateral acceleration, four wheel speeds, GPS, longitudinal and transversal slip, suspension travel, tire temperature



be strongly related to the vehicle's sound signature.

Determining this sound identity involves interpretation of subjective criteria. The tester must be able to achieve a subtle 'blend' of NVH through extensive analysis.

NVH capabilities at PolyDyam include tire and brake noise perception in the passenger compartment. A specific program has been developed to record tire/road contact noise on tracks and roads under various running and climate conditions. Recorded sound sequences are then reproduced into the vehicle, to evaluate the impact of tire noise on passengers using both an objective and a subjective approach.

A further area of expertise in NVH analysis at PolyDyam concerns the impact of lightweight components and systems on the perceived noise quality of vehicles. This aspect is particularly important for electric or hybrid vehicles, for which weight reduction is a major issue.

Training courses at PolyDyam take an innovative approach to provide a high level of technical theory and practical testing on track. A team of experts manages the teaching of the following subjects with educational vehicles on tracks: a general approach to tires and tire performance; vehicle dynamics; data analysis; simulation; safety testing; and adherence on low-grip surfaces such as snow, gravel and off-road.

Training takes place in three steps. Step one includes theory, participating in lectures on topics tailored to individual needs. Students reap benefits from the expertise of PolyDyam's engineers. The courses emphasize the participation of students based on their experience and knowledge. PolyDyam goes beyond traditional methods of teaching by using samples or demonstrator models as illustrations.

Step two is practice. Students are placed in a test vehicle with a qualified instructor. The goal is to correlate the theory with subjective feelings. PolyDyam's test vehicle has a wide range of settings to allow simulation of the theory. The car is equipped with a high-performance data acquisition system to record each trainee's testing. All these elements allow better understanding and assimilation of the subject using different neuron-receptive sensitivity.

Step three addresses analysis. The data recorded during step two is exploited to make the link between the practice and theory of trainees. This interpretation of objective measures can distinguish the behavior and the performance of a vehicle. Trainees assimilate the subject from their own experience.

This three-part approach to education includes establishing links between grip and handling; handling and vehicle performance; and the product purpose and needs of the consumer. Training is available for automobiles, motorcycles and trucks.

A team of experts can organize all events needed on track, including the demonstration of new products, testing and team building.

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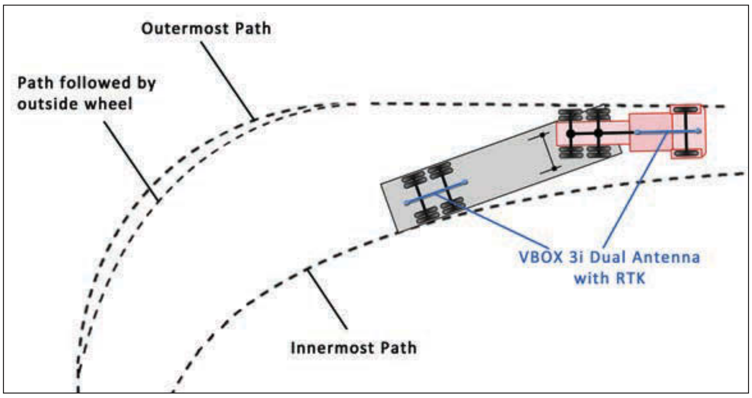
Swept width measurement

RIGHT: **TRACKING THE SWEPT WIDTH OF A HAULING AND TRAILING UNIT USING VBOX3ISL-RTK UNITS**



LCVs – longer combination vehicles – are commonly deployed in the USA, Canada and Mexico, and in some Scandinavian countries. They also operate in Australia, but at a different level entirely.

These enormous road trains comprise a hauling vehicle and four trailing units. This freighting ability is vital for some remote parts of Australia, and although there are restrictions limiting where they can go, they are an important element of the country's infrastructure.

Road trains fall outside the existing regulations that govern road-going vehicles in Australia. Consequently, they have to comply with the Performance Based Standards Scheme, set out by the National Heavy Vehicle Regulator. This references the ISO Standard 14791:2000 'Road vehicles – heavy commercial vehicle combinations and articulated buses – lateral stability test methods', so that testing standards such as approach speed and turn radius can be quantified.

Under the scheme, a road train must be tested for parameters such as tracking ability while traveling in a straight path; tail and frontal swing; and 'high-speed transient offtracking'. This last criterion sounds particularly alarming: it aims to determine the lateral distance that the back axle on the rear-most trailer tracks outside the path of the steer axle, during a sudden evasive maneuver.

With such a long and wide vehicle that has several points of articulation, there is a high propensity for it to ingress into adjacent lanes when turning a corner, and especially when exiting a junction. It is therefore necessary to assess accurately how much space is taken up during such a maneuver because there are clear safety implications for road users within the immediate vicinity – especially pedestrians and cyclists. (One of the most common ways for a cyclist fatality to occur via a heavy goods vehicle is when it turns into another road and cuts the corner intersection.)

The area an LCV uses when turning is known as the swept width, and measuring the path of the trailers as they follow the hauling unit presents quite a technical challenge. One method – quite ingenious but with obvious practical limitations – is to mount hose pipes on the trailer corners and spray water onto the tarmac as the test maneuver is conducted. The 'lines' created by the water are then measured before it dries – such a procedure in Australia requires rapid completion.

The tests mentioned above aim to determine the path-following capabilities of various parts of the vehicle in relation to the hauling unit. Racelogic designs and manufactures VBOX GPS datalogging systems in the UK. It has approached the problem and applied some lateral thinking: all these tests can be conducted by using its lane-departure warning software along with suitable hardware.

The lane-departure plug-in was originally designed for ADAS verification, enabling test engineers to determine left and right lateral ranges of a vehicle to specified lane boundaries by first mapping out the lane edges, prior to carrying out the driven test. In post-processing, 2D offsets are added to the left and right of the antenna position, referencing the outermost point of the vehicle. The processed file will then return a range of values such as the lateral range between the left and right side of the vehicle to the lane boundaries, as well as the angle of approach and the time it will take to cross them.

Applying this to swept-width testing, one VBOX3iSL-RTK GPS datalogger is placed on the hauling unit and one on a trailer. A DGPS base station is set up to provide 2cm positional accuracy. Ideally, the GPS antennas are placed on the points of interest – in this case the leading corners. If this isn't possible, offsets are applied via the software to the antenna positions, so that the points on the vehicle from which measurements need to be taken can be referenced.

Once the data from the driven test has been collected, the VBOX file processor software is used to combine the data captured by each logger. Each file consists of the path taken by the tractor and trailer units, and when processed the entire swept width can be measured.

Using the system, setup time in comparison with traditional methods is greatly improved. The ±2cm positional and distance accuracy means that quantifiable testing and validation is possible to a degree previously unachievable.

BELOW: **ROAD TRAINS CAN MEASURE IN EXCESS OF 50M**

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Quote ref VDI 005

Advanced ride control

MagneRide, from BWI Group, is widely recognized as one of the world's most advanced production ride control systems. Using fixed-orifice dampers whose response can be changed by electro-magnetically controlling the rheological properties of the damper fluid, MagneRide enables vehicle engineers to achieve an exceptional combination of ride and handling performance. Unlike conventional valve-based, semi-active suspension systems, MagneRide is mechanically simple with no valves or other small moving parts.

MagneRide's electronic control architecture means that damping development is carried out through software and calibration changes via a laptop computer, rather than through the repeated dismantling of prototype units and reassembly with modified hardware. This reduces development times and enables greater scope to find the optimum damping calibration for the best ride and handling.

For vehicle manufacturers, the ability to change the damping characteristics simply by recalibration means that vehicles that share a common platform can easily be optimized to suit regional variations in road surface, differing customer tastes, and even to reflect the different attributes of sister brands that use common architecture.

In the case of the Audi TT coupe, widely different characteristics were achieved by simple calibration changes, to successfully accommodate the requirements of all models, from the base diesel to the high-performance TT RS.

"Introducing MagneRide suspension onto a vehicle is as much about integrating the electronics as tuning the suspension hardware," explains BWI's manager, forward engineering controlled suspensions, Olivier Raynauld. "This means that once the controller communication protocols and diagnostics are in place, the damping performance can be quickly optimized for each individual model."

In addition to faster development and greater optimization of each additional model, manufacturers can also reduce the variety of damper specifications required in the assembly plant and throughout the supply chain, including the aftermarket.

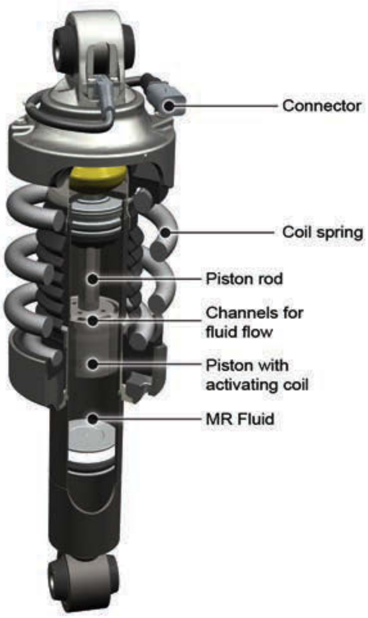
MagneRide technology is featured on a wide range of vehicles aimed at the most discerning customers, including Audis, Ferraris, Cadillacs and the Evoque from Jaguar Land Rover. In a market that continually subdivides into new segments, categories such as prestige sporting all-terrain vehicles have created new challenges for suspension engineers, who strive to deliver taught handling and good ride comfort regardless of road surface. The Evoque is the first vehicle in this sector to feature MagneRide.

"Land Rover wanted a new level of suspension control for the Evoque," says Raynauld. "MagneRide dampers provide that control across all surfaces and under all conditions – effectively removing the need for chassis engineers to compromise between ride comfort, body control and handling precision – whether driving over rough country roads or smooth highways."

MagneRide dampers provide a fast, smooth, continuously variable damping action with a typical power consumption of less than 20W per damper. They respond in real time to road conditions based on inputs from sensors monitoring wheel position, steering angle, vehicle speed, engine speed, gear ratio and external temperature. Many of these sensors are already fitted to the vehicle to support other systems such as ABS and dynamic stability control.

LEFT: **A GENERATION 3 MAGNERIDE CONTROLLED SUSPENSION SYSTEM IS NOW AVAILABLE FROM BWI**

BELOW: **MAGNERIDE TECHNOLOGY IS FEATURED ON THE AUDI R8**



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Quote ref VDI 006

Flexible EPS architecture

TOP: **IN ORDER TO MEET FUTURE VEHICLE DEMANDS, NEXTEER CARRIES OUT R&D INTO POSSIBLE NEW MOTOR CONFIGURATIONS**

MIDDLE: **ITS ELECTRONIC ARCHITECTURE FOR EPS SYSTEMS IS IMPLEMENTED INTO A NEW GERMAN VEHICLE**

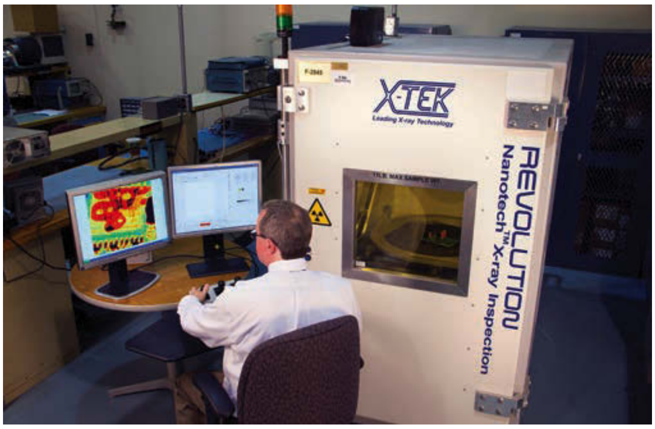
BELOW: **THE COMPANY ALSO HAS CAPABILITIES IN ELECTRONICS TESTING**

Nexteer's innovative electronic architecture for electric power steering (EPS) systems has entered production in a new state-of-the-art premium German vehicle. The customizable 12V electronic architecture supports EPS applications across all passenger vehicle types, from low-cost microcars to high-specification luxury SUVs.

The highly flexible platform adapts to suit individual customer requirements, enabling manufacturers to introduce new, increasingly complex steering functions, such as lane-keeping assistance. To provide the substantial increase in processing power needed, Nexteer is using a new family of ISO 26262-compliant dual-core processors, which are scalable in memory size to meet the demands of specific projects.

At the entry level, a simplified control platform with only the essential features provides a cost-effective system for economy cars and emerging markets. For premium applications, the modular nature of the architecture allows the build-up of additional features, supporting a wide range of options and providing a development path into the future.

The new architecture was made possible by Nexteer's unique combination of in-house capabilities – uniting electronics, control software and mechanical engineering expertise within a single company. This frees the designers from many of the constraints imposed by standard hardware and components from external sources, enabling greater levels of optimization through increased understanding of the capabilities of the individual elements.



Well ahead of any product engineering, Nexteer's multidisciplinary innovation group analyzes the likely impact of future trends and undertakes the fundamental creative work necessary to meet the expected challenges. This may involve exploring new motor configurations or sensor technologies, for example, in order to overcome the limitations of existing technology.

Nexteer believes that this emphasis on conceptual work distinguishes the company from many Tier 1 suppliers. "As an engineer, you really can make a difference here," explains Bertram Moeller, EPS technology manager. "Although cost-effective application engineering is clearly important, our competitive advantage comes from our technical innovation."

It takes a highly energized talent pool to sustain the necessary momentum across so many complementary technologies. Of the company's 10,000 global staff, 1,200 are highly qualified engineers, with 700 of those dedicated to the various EPS technologies. "We are continually adding the brightest and most capable engineers to our various regional technical centers," says Moeller. "At present, our focus is on the USA, but at other times it could be in Europe or Asia. As the team expands, we continually create exciting new career opportunities."

Nexteer operates in a highly technical and fast-paced environment subject to constant change, whether in regulatory framework, market expectations or technical developments. "It's a complicated picture, with changing standards for functional safety, a proliferation of new functional requirements, greater demands on ECU memory, and the evolution of new communication protocols," says software engineering director, Mark Haller. "Nexteer's strength and long-term stability is rooted in its vigilance – spotting industry trends early – and its investment in high-quality people capable of meeting the future challenges by inventing the next-generation technologies."

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Effective EPS evaluation

MTS Systems Corporation recently collaborated with Nissan Motor Company to create an efficient, hybrid simulation environment for accelerating the development of electric power steering (EPS) systems. Deployed at the Nissan Technical Center, this laboratory-based solution has proven an effective means for gaining highly accurate and repeatable steering effort measurements earlier in the vehicle development cycle – well before any vehicle prototypes are available for track testing.

The evolution of EPS technology is enabling improvements in vehicle efficiency, handling, comfort and safety. The complexity of these new systems, however, poses an array of new challenges for vehicle developers. Numerous additional tuning parameters, hard-to-model components and complex interactions with other vehicle subsystems make timely characterization, tuning and evaluation of EPS systems difficult to accomplish with standard tools and test methods. This is especially problematic for vehicle development teams already under tremendous pressure to reach the test track earlier for accelerated validation cycles with minimal rework.

To help Nissan overcome these testing challenges, MTS developed a real-time EPS simulator, featuring innovative mechanical hardware-in-the-loop (mHIL) technology. While conventional hardware-in-the-loop testing combines virtual models with electronic hardware, such as power control units, mHIL solutions combine mechanical testing hardware and virtual models in a real-time control loop. Specifically, a dynamic computer model of a vehicle draws low- to mid-frequency dynamics from a physical test rig applying mechanical loads to a vehicle component. Data exchange occurs in real time, enabling the vehicle model and the test rig to act on new data with each clock tick. In this way, the physical response of the component affects the behavior of the model – and vice versa.

The Nissan mHIL Steer Simulator integrates an optimized MTS five-channel test rig, featuring ultra-low torque measurement capabilities, and a well-parameterized CarSim vehicle model into a tightly synchronized, high-speed HIL environment. The physical test rig accommodates all the necessary hardware – steering rack, column, I-shaft, tie rod ends, controls and wiring – to perform EPS rack pre-tuning, characterization, and steering effort (feel, on-center) evaluation.

Using the steer simulator, Nissan engineers are able to 'drive' a vehicle under development through a virtual environment while subjecting its physical EPS system to mechanical forces and motions, making it possible to set up, characterize and perform full-vehicle evaluations of new electronic steering systems from a single software interface. The simulator's ability to replicate real-world conditions was evaluated by comparing the vehicle behavior calculated by CarSim, measured tie rod axial force and steering torque with data acquired from an actual test track. All data generated by the mHIL system demonstrated good correlation to the track data for subsystem characterization and overall vehicle evaluation.

Nissan's steer simulator demonstrates the value mHIL technology holds for developers under pressure to accelerate programs and cut costs. It allows for physical inputs from difficult-to-model components and subsystems, as well as the subsequent simulation of their interactions with other vehicle systems. In so doing, mHIL generates high-fidelity vehicle, system and component behavior data much faster and more cost-effectively than traditional standalone testing or analysis. As a result, validation and optimization of designs can occur earlier, with fewer and faster iterations, well before the first prototype hits the test track.

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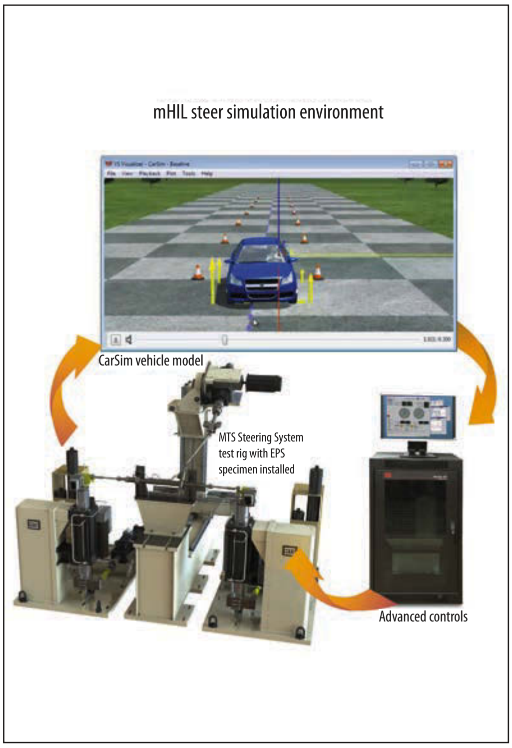

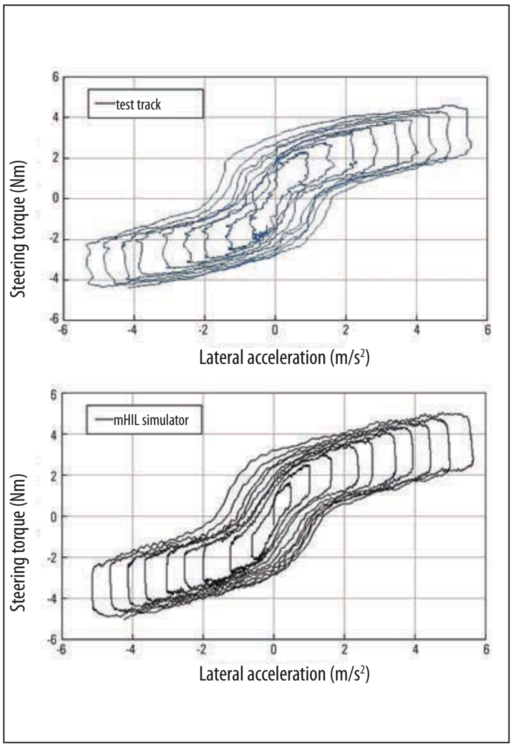

LEFT: **THE REAL-TIME MHIL STEER SIMULATOR ENABLES EPS RACK PRE-TUNING, CHARACTERIZATION, AND STEERING EFFORT EVALUATION EARLIER IN THE VEHICLE DEVELOPMENT CYCLE – WELL BEFORE THE AVAILABILITY OF FULL VEHICLE PROTOTYPES**

RIGHT: **DATA GENERATED BY THE MHIL SYSTEM USING CARSIM DEMONSTRATED GOOD CORRELATION TO ACTUAL TRACK TESTING FOR SUBSYSTEM CHARACTERIZATION AND OVERALL VEHICLE EVALUATION**

Test tool for FCW

RIGHT: **DEWE2-A4 SEAT-MOUNTED KIT FOR TESTING A FORWARD COLLISION WARNING SYSTEM**

Most modern vehicles are equipped with complex driver assistance systems such as forward collision warning (FCW) systems. An FCW system must be tested according to the guidelines of the National Highway Traffic Safety Administration (NHTSA) before being approved for the US market.

NHTSA defines three driving scenarios in which FCW technology must be assessed. In the first, a subject vehicle (SV) approaches a stationary principal other vehicle (POV) in the same lane of travel. The second test begins with the SV initially following the POV at the same constant speed. After a short while, the POV stops suddenly. The third test consists of the SV, traveling at a constant speed, approaching a slower moving POV, which is also being driven at constant speed.

The goal of these tests is to verify that the FCW system warns the driver early enough to avoid a crash. For example, the FCW must occur when the TTC (time to collision) is greater than 2.1 seconds, depending on the maneuver.

Though this sounds easy to test, it is in fact challenging. For each vehicle, data from multiple sensors and sources must be acquired synchronously: GPS data of the vehicle positions and trajectories, CANbus data of vehicle speed and yaw rate coming from the vehicle, analog data from accelerations and acoustic FCWs, video data from optical FCWs and test documentation, and also digital data.

But what's even more challenging is having full synchronization between the two vehicles during the measurement in order to accurately calculate the distance between the vehicles, their trajectory and speed. With the DEWE2-A4 measurement system and its SYNC-CLOCK technology, Dewetron provides a turnkey solution.

The synchronization of the measurement systems between the two vehicles is done by GPS-SYNC. This technology uses the PPS (pulse per second) from the GPS signal and a highly precise clock in each data acquisition system. Since it is necessary to see important values such as the distance between the two vehicles and their speed during the tests, live measurement data is transferred between the two vehicles using a wireless network. The calculations and combinations of the measurement data of the two vehicles are executed directly in the SV and can be visualized so that the driver or technician can immediately see all the important values during measurement.

The data acquisition software automatically takes care of the synchronous acquisition of all sources and shows live data online during the measurement in freely customizable data visualization instruments (digital and analog meters, time-based recorders, GPS map). The 3D display is capable of showing the relative positions of the two vehicles.

The optical FCW and the surrounding conditions are acquired with a synchronized camera. The acoustic warning of the FCW system is acquired using an analog ICP microphone. An online FFT calculation can be used to filter and isolate the input signal so that only the acoustic warning is detected.

The sequencer is used to automate the tests and monitor characteristic values to immediately indicate whether the test was successful, if it has to be repeated, or generate final reports after the test cycle has been completed.

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Kia pro_cee'd

GT Tech 1.6 T-GDi

JOHN MILES IS IMPRESSED BY KIA'S FIRST EUROPEAN-STYLE PERFORMANCE HATCHBACK, THE PRO_CEE'D GT

"We feel that for the UK, a 17in wheel-and-tire package might have been a better option, if the front discs could have been housed within"

The interior of the 2014MY Kia pro_cee'd GT has the ambience of a German-built car. The quality is there and certainly the equipment, from the tight-fitting Recaro seats, to the ESC, EBD, brake assist (BAS), TPMS and hill-start assist (HAC), plus the usual connectivity refinements, and excellent, six-speaker ICE. All this for under £20,000 on the road in the UK, if specifying the basic GT model. Satnav, rear-view camera, heated steering wheel and every other conceivable bell and whistle come on the GT Tech version (£22,495) tested here. Athletic-looking curbside appeal is undoubtedly there too, not to mention the 5-star Euro NCAP rating and usual Kia seven-year, 100,000-mile warranty.

The powertrain performance is frankly astonishing. Thanks to direct fuel injection, variable valve timing, and integral-with-manifold, twin-scroll turbocharger, Kia has extracted 201bhp at 6,000rpm from just 1.6 liters, and more importantly 265Nm of torque all the way from 1,750rpm to 4,500rpm. Small engines are necessarily more refined, and this unit is no exception. Idle is almost inaudible, and throttle calibration the best we have experienced in the light throttle/clutch take-up phase so often jerky elsewhere. Thereafter response is smooth, powerful and immediate, with little point in exceeding the max power point to get all the performance needed. The claimed 0-60 in 7.4 seconds and 143mph maximum are clearly attainable. The 6-speed shift is pleasantly precise, and slick enough.

In spite of the around average 15.3:1 steering ratio (2.85 turns lock-to-lock), there is somewhat less immediate cornering bite at low to medium speed than one might expect from a car in this segment. However the EPS was much liked because it is precise, linear, and confers less excitable high-speed corner entry than some systems. It also helps the very secure lateral-response phasing – absence of delay – between front and rear cornering bite. At higher speeds, one occasionally notices a very slight lack of aligning torque around the straight ahead, so typical of the styling/marketing-driven 18in x 7.5J alloy wheels, which in this case carry Michelin Pilot Sport 225/40 ZR18 92Y tires. Spring and bush rates are slightly up from standard, and there are longer front bump stops for roll and big-bump control. But the major change is in damping rates, which are up massively by a total of 40% at the front axle and no less than 250% at the rear, in conjunction with a 1mm larger diameter rear anti-roll bar.

THE GT DOES WITHOUT THE SWITCHABLE 'FLEX STEER' FUNCTION OF THE STANDARD PRO_CEE'D

Much of the chassis development was done at the Nürburgring, so its no surprise to find iron body control in all primary body modes. Handling is well balanced, extremely secure and without excessive understeer. Cornering power is also very high indeed, with understeer appearing only towards the absolute limit. Braking is appropriately powerful, well modulated with not too much initial bite, and fade-free.

On decent surfaces the car has flowing primary ride motion through the Mando-supplied suspension, but when it comes to some of the more subtle comfort criteria on UK roads the picture is a little different, because as the dampers heat up, and the road surfaces deteriorate, a somewhat 'wooden' undertone can pervade, especially on concrete and Norfolk's rippled and chipped surfaces. We feel that for the UK, a 17in wheel-and-tire package might have been a better option, if the 300mm diameter front discs could have been housed within. Impact thump and vertical jerk can be high, while high-frequency shake/shudder sometimes appears on broken and rougher surfaces, especially at moderate speeds. Rough textures can further impair the feeling of quality via a tingling sensation through the steering wheel. That said, secondary ride is just about adequate on the UK's more challenging surfaces. Given the aggressive wheel-and-tire package, the road (and wind) noise is rather better suppressed than expected and acceptable for a hot hatch.

With this much mid-range torque, and without the benefit of a RevoKnuckle/Superstrut-type front suspension, one might have expected a lot of torquesteer. In this respect the car is extremely well behaved. A getaway that breaks traction can result in power hop (wheel/powertrain tramp), which is quite dramatic and sounds potentially damaging for the drivetrain. The average 35.6mpg recorded by the delivery driver was soon reduced to 32.5mpg after the road test mileage – fuel use that is about average for a hard-driven GTi.

The Kia pro_cee'd GT 1.6 T-GDi is built in Slovakia and destined for European markets only. Overall it is a very convincing package and, for this reviewer, clearly better than most European rivals. It is well styled, well built, and has a particularly impressive powertrain. The steering, handling and grip are seriously good. Secondary ride is acceptable but as always could do with being a little more cushioned.

Perception vs reality

JOHN HEIDER INVITES YOU TO JOIN THE DEBATE OVER RECENT ADVANCES IN VEHICLE DYNAMICS

> **"In today's business climate, maintaining vehicle dynamics performance while improving cost is attractive to most high-volume OEMs"**

An industry-insider friend of mine informed me recently that he thinks vehicle dynamics technology on production cars is stagnating. He even thinks the future concepts and ideas he sees put forth are not unique or groundbreaking. "Really?" was the thought that came to mind. What could possibly lead one to this conclusion, or more importantly, is this accurate? Well…in the spirit of perception being reality, some explanations are in order.

Vehicle dynamics attribute performance can be classified into two major categories: customers' satisfaction with their vehicle's ride, handling, steering and braking performance; and emergency handling-safety performance that actively helps customers overcome their own errors, or the errors of others. Possible explanations for my friend's conclusion can be drawn from both categories.

On the customer satisfaction side of the equation, my friend's perception may be accurate, but I'm not sure it means technology has been stagnating. Rather, I think that technology advances have been focused on delivering existing levels of customer satisfaction with vehicle dynamics while enhancing the performance of other attributes. Examples include rubber compounding and construction advances delivering lower rolling resistance tires without compromising dry, wet or low-μ performance; EPS algorithms enhancing feel and reducing warranty costs; and stability control systems developed to mimic the performance of hardware-based limited-slip differentials or torque-vectoring systems. Implementation of these technologies has not gone faultlessly, but in the realities of today's business climate, maintaining vehicle dynamics performance while improving cost or fuel economy is attractive to most high-volume manufacturers.

When considering the safety aspects of vehicle dynamics, advances in technology have been rapid in recent years and will continue to progress quickly. Having said that, these advances are not always easily demonstrable to a customer and generally do not enhance driving enjoyment for the enthusiast or non-enthusiast driver. Panic brake assist and active braking? They sound great for the guy following behind me. Lane warning/active lane keeping? No thank you – I prefer to pay attention and supply my own steering input. Steer-by-wire and brake-by-wire? Think I'd prefer to wait for a ride in an F-22 to try these out.

The capability of stability control systems has also grown tremendously to the benefit of all drivers – the number of modes, enthusiast settings and continual ghosting in the background has saved more than a few crumpled fenders. All these advances have made our vehicles safer than ever and cannot be overlooked.

So what is next on the horizon for production cars? Are we going back to the future with four-wheel steering systems and continually improving actively controlled suspension systems? Is steer-by-wire going to achieve widespread acceptance? What are the vehicle dynamics expectations for an autonomous vehicle? What would be possible if we actually knew the real-time loading and slip condition of each tire? The possibilities seem endless and 'stagnant' certainly isn't the first word to come to mind.

I'd like to issue a challenge to readers. On June 24-26, 2014 the publishers of this magazine are hosting the annual Vehicle Dynamics Conference in Stuttgart. They have the stated goal of making this simply the best vehicle dynamics conference ever assembled. In order to achieve this, attendees are needed at the sharp end of the vehicle dynamics pyramid – from the OEMs and leading suppliers – for some open, honest, opinionated and engaging discussions of the present and future state of vehicle dynamics. No corporate secrets need be revealed – just bring your opinions and candor and be prepared to discuss the perception and reality of the current state of vehicle dynamics in the industry.

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

ON THE WEB
Further comment from Heider at VehicleDynamicsInternational.com

THE F-22 FORMS THE WORLD'S ONLY OPERATIONAL 5TH-GENERATION FIGHTER FLEET. BY-WIRE FLIGHT CONTROLS AND VECTORED THRUST GIVES IT AGILE HANDLING

LOCKHEED MARTIN

Is this a setup?

CARS WE DROVE RECENTLY THAT DIDN'T BEHAVE AS THEY SHOULD

CASE 27: FORD FIESTA ST MOUNTUNE, BY GRAHAM JOHNSON

Never believe a word those consumer-press motoring journalists write. I've said it to anyone that will listen to me for years because – with very few exceptions – these 'experts' are often inexperienced in their trade and seemingly interested only in cars that oversteer (the exact thing that a road car should absolutely not do).

And yet the other day, there I was on the telephone trying to buy a Ford Fiesta ST without ever having driven one. The aforementioned folk had raved about it, so I was dead set on buying an ST as a toy. Indeed, you could say I became obsessed with getting one because finding one was nigh on impossible. Such is the demand for the little turbocharged shopper that the waiting time for a newly built one is four months, and I wasn't about to pay the premium that used ones are fetching.

Thanks to the delay in sourcing an ST, I finally had a chance to drive a press car before I'd parted with my cash and, well… Never believe a word those consumer-press motoring journalists write! Here's a car that could ride well (why not? The regular Fiesta does), and yet the marketing men have clearly been at this thing because on UK roads it's one of the most unsettled cars on sale today. It rests after 50-55mph, but at urban speeds the only appropriate word for the ride quality is 'unnecessary'. It ruins an otherwise pleasant car.

'Pleasant?' Well, it's not a hot-hatch legend, that's for sure.

The steering is unevenly weighted (over-light just off-center) and yes, uncommunicative. The message about grip comes from tire squeal on a dry road and running wide on a wet road. Throttle adjustable it may be, but there's a little more body roll when it comes to direction-change than one would otherwise expect of a hot hatch (and especially one so firm – it shows you that it's the damping at fault here).

Now, if the above reads as rather damning, forgive me: I'm more than a little disappointed, that's all. Let's not forget, this car made a major contribution to Ford's double-win in our 2013 Awards. And it's not a bad car: actually, it's quite good. But great? Nothing with such an unnecessarily restless ride could ever be great.

Oh, and in case you are wondering, I bought a Suzuki Swift Sport instead. The ride quality is remarkable for such a car and it's properly throttle adjustable too. It's an absolute hoot – just as a great hot hatch should be!

SPECIFICATIONS

Ford Fiesta ST Mountune

Engine: 1.6-liter turbo I4. 212bhp and 320Nm on time-limited overboost

Suspension: MacPherson strut front, twist beam rear

Geometry: Front camber -1.2°, toe in +0.2°, castor 4.5°; rear camber -0.6°

Steering: TRW EPS. 2.32 turns lock-to-lock, ratio 13.69:1, turning circle 11.2m

Brakes: Tandem master cylinder. Front – vented discs 278 x 23mm, calipers with 54mm pistons. Rear – solid discs 253 x 10mm, calipers with 34mm pistons. Switchable ESC with EBD and EBA

Wheels/tires: 7.5J x 17in alloys with 205/40s

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