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Sports car special

Car of the Year

PLUS

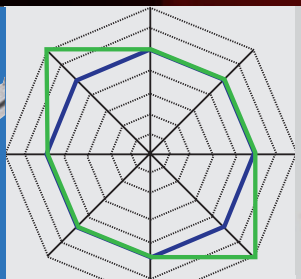
McLaren's dynamics tech

Opel's intelligent LSD

SL & Boxster chassis

and what we thought of the Ferrari California

VEHICLE DYNAMICS EXPO 2012
Full conference program inside



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A NOTE FROM THE EDITOR

For some time now we've been beating the drum for simplicity. In the face of rising power outputs and ever-greater levels of complication in the drivetrain, suspension and steering, cars that take a less-is-more approach and offer fun at legal speeds have been confined largely to the low-volume manufacturers.

That's why we believe the Subaru BRZ and its twin sister, the Toyota GT86, are deserved recipients of the 2012 *VDI* Car of the Year Award. With 80 horsepower *fewer* than the latest super-coupe from Opel/Vauxhall, the Japanese duo are well and truly 'off-trend', at least as far as the European OEMs are concerned. But the signs from Japan are good: Mazda has a new emphasis on all things lightweight, and a track record in RWD roadsters. Honda, too, seems keen to rediscover its mojo. Let's hope this heralds the start of a new wave of fun-to-drive machinery, and one not just confined to sports cars. Case in point: I tried the VW Up recently, and it's a great drive. Best of all, lighter and slower also means greener, so we can sell the concept to CO_2-obsessed marketing departments!

You can hear from Subaru at Vehicle Dynamics Expo in Stuttgart, on June 14-16, where a fabulous, free-to-attend conference program and an absorbing mix of new chassis development technologies await your attention (the show preview starts on page 46). See you there!

Graham Heeps

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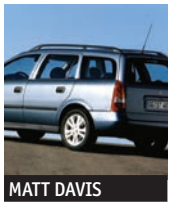
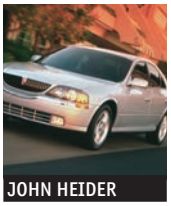
CONTRIBUTORS... AND THEIR CARS



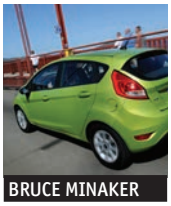
MATT DAVIS
Matt is in love with his personal, 2001MY Opel Astra 1.4-liter CDX station wagon, which he says has the best directional stability ever felt in an everyday Astra, plus perhaps the best three-spoke airbag-toting steerer ever used in the class!

GRAHAM HEEPS
The latest addition to the editor's driveway is a Ford S-MAX. A recent vacation once again underlined the big seven-seater's fantastic composure on lumpy UK roads, making it hard to make a case for the optional CES setup.



JOHN HEIDER
Among John's five-strong fleet is a 2000 Lincoln LS V6. "It's the best RWD chassis Ford has ever done," he says. "Management got it right initially by giving Lincoln what today would be a world-class RWD platform, then got it wrong by killing it prematurely."

JOHN MILES
After more than a year's work, John's Austin *7* Ulster is complete at last. "It pulled 6,300rpm in top gear (83mph), two-up on the way back from the MOT – it was a pleasant surprise!" says John. You can read all about this fascinating project – this is no ordinary vintage car – in his column (*p12*)



BRUCE MINAKER
One year and 15,000km on, Bruce is still loving his lime-squeeze-green Ford Fiesta with DCT. "It's a shame that Ford didn't add optional push-button shifting, like they do in the new Focus," he adds. "And having seen the Fiesta RS concept in Detroit, I'm definitely interested in a test drive!"

Cut CO_2 by cutting weight by a third

In today's automotive industry, every gram of CO_2 emission counts. That's why reducing vehicle weight is so important. But that's easier said than done for drive line components, where demands on performance and durability are high.

SKF product development engineer Paolo Re and his SKF team have a solution; the SKF Low Weight Hub Bearing Unit. By minimizing the use of steel and replacing it with light alloy, weight is cut by almost one third without compromising performance or bearing life. This innovative hub bearing unit suits premium cars equally well as light trucks and electric vehicles. The bottom line is reduced emissions and fuel consumption. This solution may also help automotive manufacturers avoid CO_2 fees.

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Twin peaks

WHEN SUBARU AND TOYOTA DECIDED TO BUILD A SPORTS CAR, THEY THREW 21ST CENTURY CONVENTIONS OUT OF THE WINDOW. **GRAHAM HEEPS** FINDS OUT MORE

The Subaru BRZ and Toyota GT86 are surely the most hotly anticipated cars of 2012. Not because they're the most powerful, or expensive, or glamorous models you'll see this year, but because they represent a return to a concept some of us thought might have gone for good: a simple, relatively low-powered, rear-drive sports car with the emphasis on the fun factor.

These near-identical twins are born of a cooperation between Toyota and Subaru's parent, FHI. The official line is that Toyota took care of product planning and exterior/interior design; the two companies worked together to develop the technology concept; Subaru then did the detailed engineering design and development, plus durability testing; before Toyota joined back in for road testing and chassis tuning.

Speak to engineers from the two organizations and both sides will talk up their role in the car's genesis. We're in no doubt that in engineering terms, this was Subaru's program, led by project general manager, Toshio Masuda; but nor do we doubt the passion and commitment of Tetsuya Tada, who as chief engineer led the project from the Toyota side. For as Tada himself says, "It deviates somewhat from standard Toyota practice, by ensuring that 'fun' and 'cool' reign supreme, even over the pursuit of traditional strengths such as 'ease of use' and 'convenience'."

So what exactly do we have here? The basics are as follows: a front-mid-engined, rear-drive 2+2 powered by a 2-liter, normally aspirated, 197bhp Boxer four-cylinder engine that sits low in the car thanks to a low-profile oil pan. Another major mass, the fuel tank, lies ahead of the rear axle. The resulting front/rear weight distribution is 53/47.

"People say that 50/50 weight distribution is best for a sports car, but I don't necessarily think so – it depends on the power," says Tada.

"Personally I think there should be a little more weight over the front to give you that initial feel from the steering [on turn in]. If the car had much more power, say more than 300 horsepower, then the weight distribution should be more rear-biased." He adds that Toyota has no plans at present to make a higher-powered version, however, instead inviting aftermarket tuners to develop performance parts.

Given that it's not driver-adjustable with the press of the right foot, Tada views the center of gravity as more important to the car than its weight distribution. At 459mm, the BRZ/GT86's figure is impressively low – midway between a Porsche 911 GT3 and a Cayman, according to Toyota's figures. Also low is the driver's hip point of 400mm.

"It's a sports car, but not in terms of numerical performance – laptime, or cornering speed," says Tada. "I wanted some human feeling to the dynamics, that's the big difference from current sports cars. This pursuit of numerical performance has made sports cars very expensive, meaning that only rich people can enjoy them. I think this is a boring situation! So I abandoned some of the usual technologies

SPECIFICATIONS

Subaru BRZ/Toyota GT86
Dimensions: 4,240mm (L) x 1,775mm (W) x 1,285mm (H)
Wheelbase: 2,570mm
Track: 1,520mm (F), 1,540mm (R)
Engine: 1,998cc DI Boxer-4, 197bhp @ 6,800rpm, 205Nm @ 6,600rpm
Curb weight: 1,238kg
Suspension: MacPherson strut front, double-wishbone rear. Mitsubishi springs (25N/mm BRZ, 23N/mm GT86). Showa dampers.
Steering: Toyota coaxial EPS, gear ratio 13:1
Brakes: Hitachi 277mm ventilated (F) and 286mm solid (R) discs, or 294mm ventilated (F) and 290mm (R) ventilated discs. Bosch ABS/ESC.
Wheels/tires: 16 x 6.5J or 17 x 7J alloys with 205/55/R16 or 215/45/R17 rubber

DEVELOPMENT NOTES: **TOYOTA WILL SELL THE CAR IN THE USA AS A SCION.** THE '86' MONIKER ALSO REFERENCES THE ENGINE'S 86MM X 86MM BORE AND STROKE. **THERE'S ENOUGH SPACE IN THE LUGGAGE COMPARTMENT WITH THE SEATS DOWN FOR A SET OF FOUR SLICK RACING TIRES.** BOTH CARS ARE BUILT BY SUBARU IN ITS GUNMA FACTORY IN OTA-CITY, JAPAN. **THE FIRST MULE CAR WAS BASED ON A SHORTENED LEGACY WITH A LOWERED ENGINE LOCATED SLIGHTLY FURTHER BACK IN THE CHASSIS**

CONFIDENCE BOOST

With its leading role in engineering the BRZ and GT86, Subaru's engineers talk with immense pride about their achievements: "We did not contribute to it," they point out, "we did it."

It seems that their success has given them renewed confidence in their AWD expertise, which, they say, was instrumental in the RWD sports car's creation.

"We brought very good knowledge from our AWD cars to the BRZ, including weight management," says Masuda. "We came to realize that all kinds of elements are ideally balanced in our all-wheel-drive package, including heat management, oil management, and tire performance."

NEWS-IN-BRIEF

The recently announced 2013 SRT Viper will get Pirelli tires as OE fit for the first time. In addition, two-mode Bilstein DampTronic Select dampers will be standard on the GTS version of the coupe, which is powered by a modest 8.4-liter, 10-cylinder 640bhp engine!

TRW has been awarded new business for its next-generation Electric Park Brake (EPB) technology, with two major North American-based vehicle manufacturers expected to launch the system in the 2013 model year. TRW launched the first integrated caliper EPB in 2001; the latest systems will feature TRW's Gen 5 ECU.

In a four-year deal, the IZOD IndyCar Series has chosen Brembo to supply the brakes to its new Dallara DW12 chassis. Unlike in previous years, the same brake system will be used by all teams for both ovals and road courses. Brembo has engineered a six-piston, monobloc aluminum caliper machined from billet with titanium-radiated pistons (28/30/36mm) weighing a mere 2kg.

SOME PARTS OF THE INDEPENDENT REAR SUSPENSION WERE ADAPTED FROM THE SUBARU IMPREZA

found in current sports cars – four-wheel drive, powerful, large-displacement engines, and high-grip tires. I said no to all of these.

"The suspension is entirely passive," he continues. "I tried to reduce any computer control in this car – it's back to basics, low-technology. It has stability control, but you can completely switch it off. Instead, we were tough on weight and the center of gravity."

The partners decided on a MacPherson strut front suspension to keep the weight down, with a strut tower bar for extra rigidity. The L-shaped lower arm has been reversed front/rear to allow the engine to be mounted as low and as close to the vehicle's center as possible. The cross member has been specially designed to fit in the limited space between the oil pan and the exhaust. And to help keep the hood line low, the coil springs have been attached at the sides of the wheels, with the strut mounts positioned as low as possible.

"The front suspension design is all-new," confirms Masuda. "The top mounts are low, but the stroke of the suspension is still equal to other Subaru models."

Stability considerations led to the choice of a double-wishbone setup at the rear axle, where some parts of the suspension were adapted from the Subaru Impreza. The differential opening in the subframe has been made larger in pursuit of a lightweight design. To ensure rigidity, the cross sections of the differential opening were enlarged. The differential itself comes from the Toyota Mark X, while a JTEKT Torsen LSD is an option.

Also borrowed from other Toyota models is the coaxial EPS steering column. The car's creators say that the low column-tilt angle of 16° is as good as anything else available globally, and results in a steering position in line with the low hip point. The steering gearbox has been positioned behind the front cross member and the gear ratio of 13:1

helps to give the car the desired quick responses.

Each car will be sold with a single state of chassis tune worldwide, but the BRZ's differs slightly from the GT86's, with 10% stiffer springs.

"Subaru developed the base models, sharing common components," explains Masuda. "But naturally Toyota wanted to put its own flavor on this car, especially in terms of the suspension settings, so we ended up with two different cars. It's not as easy as saying the Subaru is firmer: we think the feeling of the Subaru is more stable, it gives you more peace of mind."

The chosen settings were the result of an unprecedented road-testing program. Tada estimates that GT86 prototypes did up to 10 times more road mileage – in the USA, Canada, Japan, Australia, and Germany – than a normal Toyota development.

"This car is good on a track, but better on a public road," he enthuses. "The ride comfort is really good, especially in terms of reduced harshness from jolts from the road. The reason is that the low CofG means we don't need stiff suspension for roll control."

VDI SAYS

For years we've bemoaned the dearth of sports cars that are fun at everyday speeds. Finally, someone's done something about it. Subaru and Toyota: we salute you!

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Starlight

MERCEDES-BENZ HAS TAKEN 140KG OUT OF ITS NEW SL ROADSTER IN A BID TO GIVE THE ARCHETYPAL CRUISER A SPORTIER FEEL. BY **GRAHAM HEEPS**

Think of a Mercedes SL, and 55 years of stylish, top-down motoring comes to mind. The latest generation car, the sixth, aims to up the sportiness factor via the liberal use of aluminum and revisions to suspension and steering.

The structure is all-new, and 95% aluminum, resulting in a body-in-white that's 110kg lighter than the outgoing car's. The only structural steel part is the windshield surround, retained for its high stiffness and to give some A-pillar flexibility in a rollover situation. The retractable hardtop has a magnesium frame; used together with plastic panels, this reduces the weight of the roof by 15kg. The total weight saved across the car amounts to 140kg.

All of this is good news for the CofG height, which is 15mm lower than before, and the SL's inherent dynamic performance. The V6 version has 50/50 front/rear weight distribution; on the V8 it's 52/48, a slight improvement on before.

Aluminum parts save weight in the suspension, too. The front axle, whose track is 38mm wider than before, retains the four-link suspension of the previous-generation SL, but aluminum steering knuckles and spring links have been swapped in. The lower front-axle elements, steering gear and engine mounts are linked to an aluminum assembly carrier bolted to the body.

The rear track is also wider, by 63mm. Here, virtually all the suspension parts are made of

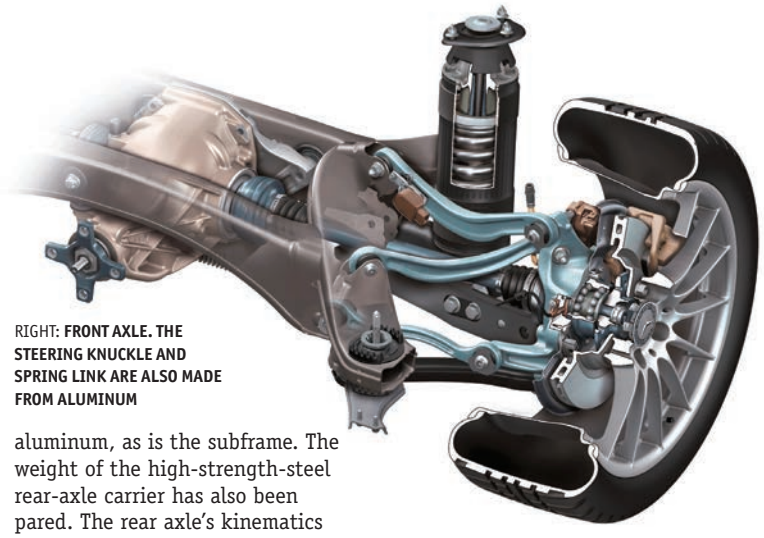
TEST LOCATIONS VISITED INCLUDED NÜRBURGRING, PAPENBURG, IDIADA, SOUTH AFRICA AND LAREDO TEST GROUND IN THE USA

NEWS-IN-BRIEF

Following 50 years with Bosch, Professor Dr Hermann Scholl is to resign from office effective June 30, 2012. He has been the chairman of the firm's supervisory council since 2003. He will be replaced by Franz Fehrenbach, who has been a member of the board of management since 1999 and its chairman since 2003.

Continental has acquired Rico Auto Industries Limited's 50% shares in the joint venture Continental Rico Hydraulic Brakes India Ltd, making it a full subsidiary of Continental. The plant in Gurgaon, near New Delhi, has been producing components for hydraulic brake systems to OEM customers in India since 2009.

At the Geneva Motor Show in March, AC revealed the 378 GT Zagato. Originally conceived by the Italian design house as the Perana in 2009, the new model features a 6.2-liter GM-sourced V8 power plant delivering 434bhp. It joins the Cobra-like MkII and MkVI in the marque's revamped range.



RIGHT: **FRONT AXLE. THE STEERING KNUCKLE AND SPRING LINK ARE ALSO MADE FROM ALUMINUM**

SPECIFICATIONS

Mercedes-Benz SL 500 BlueEfficiency

Dimensions: 4,612mm (L) x 1,315mm (H) x 1,877mm (W).
Wheelbase 2,585mm, track 1,597mm (F), 1,600mm (R)

Curb weight: 1,785kg

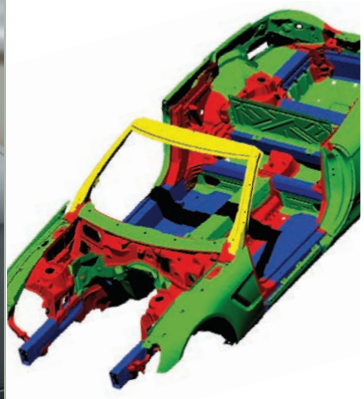
Engine: 4,663cc V8, 429bhp, 700Nm

Suspension: Four-link with DampTronic continuously adjustable damping and ARB (F); multilink with DampTronic and ARB (R). Optional Sachs ABC

Steering: TKPS belt-drive EPS, Direct Steer variable-ratio rack

Brakes: Front – ventilated and perforated discs, 360 x 36mm. Rear – ventilated 320 x 24mm. Electric parking brake. Bosch/Mercedes ABS/ESP with torque vectoring brakes to counter understeer, ACC with Distronic Plus and Brake Assist Plus

Wheels/tires: 8.5J x 18 ET35.5 with 255/40 (F); 9.5J x 18, ET47.5 with 285/35 (R)



ABOVE: CAD VIEW OF THE STRUCTURE, NOTE STEEL PART IN YELLOW

aluminum, as is the subframe. The weight of the high-strength-steel rear-axle carrier has also been pared. The rear axle's kinematics and elastokinematics have been refined for more agility, and Mercedes says that the lower forces increase comfort. An additional support linking the rear subframe bearing to the body is also said to have a positive effect on the new SL's ride comfort and NVH by increasing the level of introduction rigidity.

As a roadster and coupe all in one, Weissinger claims the SL has no direct rivals, but admits that the Porsche 911 Cabriolet was the handling benchmark for the new car.

Three separate chassis tunes are available for the regular SLs. The standard and 'AMG Sports' chassis (not to be confused with the SL65 AMG, which has its own dynamic package) are based around switchable Bilstein DampTronic adaptive dampers. The latter setup is 10mm lower, offers 10% stiffer spring struts and ARBs, and higher damping forces for tighter body control.

The third option is an ARB-free setup based around ZF Sachs' familiar Active Body Control (ABC) system.

"It's an evolution of the system in the previous car," says chief engineer Jürgen Weissinger. "In the future we will have the Magic Body Control system in the new S-Class [previewed on the F700 Concept] – this part is somewhere in between. We have adapted it a little from the predecessor, making some detail revisions to the comfort level and the damping system."

The ABC system is also fitted with a hydraulic all-round leveling system, with a cockpit switch to raise the level of the vehicle either when stationary or on the move. New to this SL is the ability to raise the car by 50mm for an increased clearance margin over rough roads or ramps. In addition, the car automatically lowers itself by up to 13mm at high speeds to minimize fuel consumption.

For the record, the SL65 AMG's chassis is based around ABC, too.

When it comes to the SL's steering, it's all-change, with an EPS system on the car for the first time. The hardware is not the ZF system from the CLS, but a new-to-Mercedes ThyssenKrupp Presta Steering belt-drive unit and a 'Direct Steer', ActivRak-style variable ratio rack, similar to that employed on the previous model. A revised ratio course is said to increase agility while reducing the maximum steering effort required when parking or turning by about 15%, reducing the lock-to-lock turns to 2.2.

The use of EPS means that an Automatic Parking Control self-parking function can be offered on the SL for the first time, as well as Steer Assist, which uses ESC data to prompt the driver where to steer in the event of instability on a split-μ surface.

"Normally with a hydraulic rack you have a gap [dead spot] around the center," comments Weissinger. "With EPS there's a smoother progression, to give you good feel."

Also new is the brake hardware, with aluminum monobloc, four-piston fixed-caliper Brembos up front and single-piston, combined floating calipers at the rear. Of particular note is a new brake cooling system at the front, developed from a series of wind tunnel and road tests. A brake air channel in the engine compartment trim guides air over the front wheel spoiler and steers it onto a guide blade. The guide blade, fixed to the front suspension link, diverts the air coming from the channel over the brake discs and out of the car. The system works in tandem with a front wheel spoiler for effective brake cooling.

VDI SAYS

Does the new SL match up to Merc's claims for a sportier drive? Perhaps. Does it match up in the style stakes to the 'Pagoda' SL we also got to drive on the launch? Definitely not!

NEWS-IN-BRIEF

As of the middle of the year, ZF will expand its plant in Tuscaloosa, Alabama. The reason is a new supply contract for chassis systems for Mercedes-Benz in nearby Vance. In addition to the model series produced there currently, ZF will also make chassis systems for the new C-Class when production starts in 2014. ZF will invest US$14.6 million in the new factory and create 85 jobs.

Volvo has selected VI-Car-RealTime, the real-time vehicle simulation environment from VI-Grade, to optimize the design of its vehicles. In particular, the Volvo R&D team selected it for its direct interface with Adams/Car.

Michelin Pilot Super Sports will be among the OE tire options for the new Ferrari F12 Berlinetta. The 740bhp car's rubber features a belt made of Twaron, a high-density fiber that's five times stronger than steel of an equivalent weight. There are also different rubber compounds on the right- and left-hand sides of the tread.

Baby boom

PORSCHE HAS BEEN TIGHT-LIPPED ON THE FINER DYNAMIC DETAILS OF ITS NEW, 981-MODEL BOXSTER, BUT **MATT DAVIS** DOESN'T TAKE 'NO' FOR AN ANSWER...

NEWS-IN-BRIEF

Racelogic is launching a more durable, waterproof version of its award-winning video GPS system. Housed in a compact, anodized aluminum casing with sealed Hirose connectors, Video VBOX Waterproof has an IP66 rating, making it ideal for use in open-top race cars or even power-boats. The system has been designed with a base flange and secure mounting holes, allowing the unit to be safely secured. *Visit Racelogic at Automotive Testing Expo Europe 2012*

BOXSTER'S 991-ESQUE MACPHERSON STRUT FRONT SUSPENSION AND EPS

As with the 911 – a car with which it continues to share much of its front-end structure – Porsche went back to the drawing board to conceive the 981 Boxster. The only elements brought over from the old model – the 987 – are the engine and gearbox, and even they have been subtly reworked for added levels of smoothness and performance.

The result is a driving experience much more engaging than in any previous Boxster model, but with no compromise to its 'everyday driver' abilities. It's a brilliant blend of track-capable handling along with the sort of inherent comfort that enables you to thoroughly enjoy the new roadster over extended highway journeys. The primary reasons for this personality shift are the newly calibrated dampers and springs from development partner Bilstein. The modifications to the elastokinematics of the front end succeed in practically eliminating old Boxster/911 twitchiness at higher speeds and reverberations on imperfect road surfaces.

While hard on it, the moment I twist the steering wheel away from the straight ahead, I'm aware Porsche has almost succeeded in matching the supreme feel of the previous model's hydraulic-assist setup with its new ZF-sourced electromechanical steering system. Into and through curves I feel a little numbness in the amount of feedback now that didn't used to be there. I oddly don't feel this vagueness much in the new 911's steering, but here in the Boxster, yes. It's still good work, the front wheel camber of -1.0° and the rear at -1.5° making themselves felt in combination with the 2.4in-longer wheelbase.

The ride is predictably firm from the Bilsteins, but it is never harsh and settles quickly when upset by potholes and the like. In addition, the mass of the car, at a lighter 1,426kg, sits lower in the physical science sense with a tangibly lower yaw point. Massive grip also provides high cornering speeds. The cornering balance is wonderfully neutral and, with Sport mode dialed up, the PSM (Porsche stability management) is configured to allow a small degree of slip angle before it kicks in. Turn it off and the intimacy of communication fed back to the driver allows me to revel in power-on oversteer.

Static overall bending stiffness in the Boxster body and chassis is reported as being 40% more rigid. This, in turn, has enabled Porsche to calibrate the Normal and Sport suspension settings to be softer, and the Porsche active suspension management (PASM) and optional brake-based torque vectoring and (also optional) rear locking sport differential actually keep the car flatter through the curves. Lateral acceleration of 1.2*g* should be routinely available from the fully optioned S model with either the standard 19in tires or the 20in Pirellis I had on mine. Assisting in the underpinnings are the Boge/ZF dynamic mounts for the engine (three) and transmission (two) for the Sport Chrono package.

The improved new generation of PASM does a better job now of monitoring movements of each wheel through the use of Skyhook software, there being today four height sensors and three acceleration sensors, whereas previously everything depended on just two acceleration sensors. Adding directional fidelity as well is the fact that each damper is now mounted to its wheel carrier at two points versus the previous single attachment point.

VDI SAYS

This very 911-esque upgrading for the Boxster has successfully helped the little Porsche graduate into a more serious league of sports car at last. And it makes us look forward to the next Cayman even more.

On the job

The magnificent 7

JOHN MILES APPLIES HIS DYNAMICS EXPERTISE TO A VINTAGE AUSTIN 7 ULSTER

Probably the most famous giant killing act performed by an Austin 7 Ulster was winning the 1930 Brooklands 500 Miles Race in 6 hours 13 seconds at an average speed of 83.41mph! No matter that the works car driven by Sammy Davis and the Earl of March was supercharged.

Post-war, the potential of an original Austin 7 in competition, or as a donor of cheap parts for a 'Special' was clear, and fired my schoolboy imagination, as it must have done for the likes of Colin Chapman, Eric Broadley, Arthur Mallock, Tony Southgate, Bruce McLaren et al.

In the 1960s, the impecunious competitor often started with an Austin 7 of some sort. I won my first speed events in one, but never had an Ulster – until now. My purchase was scruffy, but a place to start. After 25 years in the modern chassis development world, the first shock was the steering. I was left wandering down the straights, jerking the car into a corner, then reacting to mid-corner yaw deviations while wrenching at the wheel against 'stiction' mid-corner with shoulder power and approximate corrections – hopeless, and much worse than I remembered.

Most vintage cars seem to suffer from the same problem. It starts with high-ratio worm gear steering boxes. In the Austin 7 case, friction is compounded by a 10:1 ratio, and the inevitable worm gear and linkage lash around center, or in any transient maneuver. The part solution has been to increase the length of the existing steering arm with an extension/stiffening bracket, ball jointing the drag link to reduce free play, and fitting needle roller thrust bearings each end of the worm gear. The result is a 20-25% reduction in ratio, lower worm gear loads, and a far more controllable (less 'darty') car, due to the reduced response 'gain' and system friction mid-corner. Subsequently, I have discovered the works Ulsters prepared for the 1931 Mille Miglia had 16:1 steering ratios just like a modern car, so Austin engineers understood the problem even then!

Like the BMW Dixi – an A7 built under license – the chassis is a simple 'A' frame well known to be very weak in torsion, especially at the front end. Just how flexible was made clear when the bare chassis measured just 83Nm/° (yes, 83!) in torsion and 199Nm/° at the midway station. Subtle modifications plus bronze-welded rather than riveted connections upped stiffness considerably to F156/R585Nm/° but actually worsened the stiffness gradient as you can see. Hard-mounting the engine (featuring a stiffened crankcase) gave worthwhile gains at the front, but the real step change came by using a strengthened body as a stressed member and increasing the number of body-to-chassis fixings. Final numbers were 528/851Nm/° – still about a 1/15th the torsional stiffness of a modern car! In all, 9kg has been added.

"Perhaps I have reached the 7th age of man... 40bhp in a car weighing 375kg with a snarling outside exhaust, primitive suspension, and friction dampers"

Front suspension is by a transverse leaf spring attached to the chassis with U bolts a mere 90mm apart. All the roll torsion goes through this mounting, which results in the requirement for a phenomenally high double wheel bump rate to achieve acceptable roll control. My attempt at a fix has been to fabricate new 'hidden' spring mountings 330mm apart. Torsional load input to the body is now shared via two hidden rearward pointing 'A' frames. A softer spring is held between radiused blocks spaced apart vertically the exact height of the spring (similar to the roller mountings on a 1960s F2 Cooper). In this way, the spring bends over its whole length in bump and adopts an 'S' curve in roll rather than acting as two quarter elliptics. Lateral location of the whole system is now via a modified front damper.

The cable-operated brakes look standard but incorporate changes, including throwing away most of the standard heavy X-shaft and pulling the brakes on from a center pivot as has been done for many years by enthusiasts. Braking balance is determined by the relative lever lengths front and rear and will be a matter for experimentation.

A standard A7 engine gives about 13bhp. Normally aspirated production Ulsters cost £185 circa 1930 and gave 22bhp, with the supercharged version turning out 33bhp at 5,000rpm. Nowadays a normally aspirated output of 40bhp is the norm at 6,500rpm on a single 1¼in SU carburetor, rotating speeds that would have terrified the original owners. Better breathing and stronger crankshaft/conrod packages are responsible, but we have also concentrated on getting a very flat torque curve.

Perhaps I have reached the 7th age of man… a trip back in time… 40bhp in a car weighing 375kg with a snarling outside exhaust, primitive suspension, and friction dampers. Life has become too comfortable. It's back to nature with a vengeance.

Made in Italy

Audi's ice ice baby

A TRIP TO SWEDEN'S FROZEN NORTH PROMPTS **MATT DAVIS** TO PONDER THE RS5

I finally found a good use to which I can put an Audi RennSport edition car, its chassis, and its weight distribution.

Don't get me wrong: 444bhp is automatically interesting and I should love it no matter what the packaging is promised to be. But I have a special relationship with my Audi RS brothers and sisters at quattro GmbH.

The actual power-to-weight ratio is not so bad when comparing the 2013 RS5 at 8.94lb/bhp – the crux of this current RS dynamics dialog – with either a Mercedes C63 AMG Coupé or a BMW M3 Coupé. On paper they should really hammer it out side-by-side and be nearly interchangeable out on the track with no risk of losing the adrenalin joy levels you've achieved.

Alas, such is nay the case. The bosses that sire this magazine have always warned me not to "get too engine-y" when I talk dynamics, but I cannot avoid it; something has to move that boat around in order for there to be any dynamics of which to speak, so bear with me as I flex my non-engineer poetic license to stray.

The nose end of the RS5 – a fat car that I really like, actually – bears a full 59% of the car's sprung weight. And, given Audi's brand-centric quattro obsession, there's another obstacle to brilliant dynamics staring me in the face. It's an obstacle at least for anyone who wants to toss some money to the ticket taker occasionally and roar their sporty car around an actual circuit to see what she can do. I do this regularly, much to the dismay of my significant others who are frequently in the passenger seats.

The RS5 – even with the new and lighter/quicker crown-gear quattro differential, rear sport differential, 1in-lowered RS chassis versus the base A5 sled, Audi Drive Select onboard chassis calibrator, new ESC with torque vectoring, anti-roll Dynamic Ride Control, Dynamic Steering, and lord knows what other self-boasting capitalized terms and technologies – remains a bit of a lateral and in-the-curves portly farm creature. Understeer is a sloppy track companion in a nearly 4,000 lb Bavarian that is loath to budge much or be tossed around to bend to my will. It doesn't matter what I do with forced weight shifts at the steering wheel, exaggerated throttle inputs, or switching off the chassis nuns.

Out on the sportier public roads of life, all of this option-a-holic dynamism on any Audi RS is absolutely stupendous stuff. In here on a tight and calculated circuit, this RS5 is quite thick. And so I ask: why over-apply the hallowed term 'RennSport' to a set of costly cars that cannot properly Renn?

> "Everything about the RS5 dynamics that work against my joy on warm and dry surfaces become the very reasons why it would be my first choice on ice"

But then… oh, but then, Audi had heard enough of my laments and brought me to north central Sweden in the dead of winter to drive this same car in its 2013 guise on a frozen lake. This year's model gets electromechanical steering and I was afforded a set of always-good, studded 19in Lappi Winter tires – 245/35 R19.

Everything about the RS5 dynamics that work against my joy on warm and dry surfaces become the very reasons why it would be my first choice while driving on hardened cold water. Absolutely every single ingredient to helping us ballet forth together from lock to lock through the broad curves, as I stared out the side windows for the next cone, here becomes nearly perfect. I swear I nailed the long and slippery course in this RS chassis within seconds, versus the days it might take to do so in either the Mercedes or BMW direct competitors.

So, should Mercedes and BMW make their hot runners in 4Matic and xDrive trims as well? Or should Audi have a parallel RS lineup that drops quattro from the mix? Because I can't afford to buy two of these such cars to use depending on the season.

Winters up there can do funny things to a man. Funny things to a car, too.

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Car of the Year

Strictly speaking this ought to be *Cars* of the Year, but there's so little difference between the Subaru BRZ and the Toyota GT86 that they were counted together in the judging process. They needed that combined strength to fend off their rivals, too, for the Porsche 911 and in particular the impressive new BMW 3 Series ran the Japanese twins close for the category win.

Damian Harty was among those won over by the two OEMs' approach to their new sports cars: "Engineering choices driven by dynamic considerations are always going to get my vote," he said.

Accepting the award, Subaru's Toshio Masuda commented, "We always want our customers to understand the high base potential of the Boxer engine and how driving Subaru products instills confidence in the driver. The Subaru BRZ showcases our endeavors, and with an even lower engine position, it achieved an ultra-low center of gravity."

From the Toyota side, chief engineer Tetsuya Tada added, "I want people to have fun in their cars, to make their everyday life enjoyable. With the GT86, my team was focused on bringing back pure driving pleasure and I believe that this philosophy is strongly demonstrated in the final product. To have this achievement recognized is a great honor and I would like to thank *VDI* for this prestigious award."

CAR OF THE YEAR

Winner
Subaru BRZ/Toyota GT86
Highly Commended
BMW 3 Series
Also shortlisted
Ford Focus
Porsche 911

THE JURY

Paul Burnham, vehicle dynamics manager, McLaren Automotive, UK
Paul worked in F1 before moving across to McLaren Automotive, where he leads the dynamics team responsible for the award-winning MP4-12C.

Peter Cambridge, principal, Peter Cambridge & Associates
A former Prodrive engineer, Cambridge has just finished a stint with Bilstein and is now freelance once again. He currently works for a UK-based OEM.

Matt Davis, freelance writer, Italy
Italy-based, USA-born Davis has been in motoring journalism for 15 years. He is highly respected by outlets worldwide, including *Genroq* and of course *Vehicle Dynamics International*.

Damian Harty, senior research fellow, Coventry University
Harty has spent a large amount of time in industry, most recently as dynamics specialist for Prodrive's Mini WRC project, and has now moved full-time into academia.

Graham Heeps, editor, *Vehicle Dynamics International*
At the helm of *VDI* since 2005, Heeps has recently added *Tire Technology International* and *Automotive Testing Technology International* to his portfolio.

John Heider, principal, Cayman Dynamics
Formerly with Ford, *VDI* columnist Heider now runs the Cayman Dynamics consultancy, which works with OEMs, suppliers, and other companies in the transportation industry.

Supplier of the Year

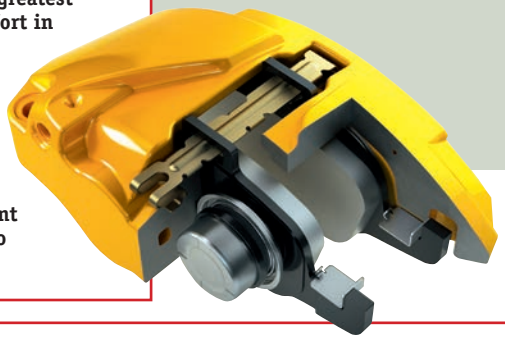
This was the closest fought of all the categories in 2012, with the eventual winner edging out a terrific challenge from Michelin by only a few points. Conti secured the title on the back of its portfolio of innovation in everything from tires to ESC.

"We are honored to be recognized by *Vehicle Dynamics International* for our products and components in the field of driving safety and dynamics for all vehicle manufacturers worldwide," said Dr Ralf Cramer, member of Continental's executive board and president of the Chassis & Safety division. "We combine mechanical engineering, electronics, and mechatronics to achieve high-performing automotive safety and dynamics technologies. By doing so we have only one single objective: to ensure that road users enjoy the greatest possible safety, efficiency, and comfort in every driving situation."

"Few companies can match the breadth of Continental's expertise," observed *VDI*'s editor and chairman of the judging panel, Graham Heeps. "Projects like the world-first EV air suspension on the Tesla Model S show a commitment to innovation rather than a desire to merely play the numbers game."

SUPPLIER OF THE YEAR

Winner
Continental
Highly Commended
Michelin
Also shortlisted
Nexteer
ThyssenKrupp Bilstein



Innovation of the Year

This year's winner in the Innovation category is a new and potentially production-feasible take on a concept that's been around for three decades: active suspension. With ACOCAR, Tenneco may have succeeded where others have failed in creating a system that isn't power-intensive or cost-prohibitive.

"ACOCAR looks to be an elegant and very energy-efficient, highish bandwidth suspension system," said judge John Miles, who was involved in early experiments with active ride control at Lotus in the 1980s and later worked on the system in Formula 1. "It takes control of primary body modes and wheel damping using existing Tenneco CES active valve technology with minimum on-cost compared with any alternative system we know of."

Acknowledging the Award, Sandro Paparelli, vice president and general manager of Ride Control Europe at Tenneco, commented, "This recognition for ACOCAR confirms the industry's desire for a fully active suspension system that significantly improves vehicle dynamics using advanced, lightweight, fuel-efficient technology."

INNOVATION OF THE YEAR

Winner
ACOCAR – Tenneco
Highly Commended
SkyActiv-Chassis – Mazda
Also shortlisted
4MF fixed-type caliper – Conti
Flexible Steering System – Ixetic

Dynamics Team of the Year

A special mention should be made here for Mazda, whose innovative SkyActiv-Chassis program has been one of the chassis development highlights of the past 12 months. But Toyota's dynamics team has secured the category win not just because of the GT86, but also because of the new emphasis on driving performance that seems to be filtering down through products such as the latest Lexus GS.

"Some time ago our president, Akio Toyoda, challenged us to make 'even better' cars," explains Bruno Reinke, Toyota's European executive responsible for Chassis & Dynamics. "This award shows that we are heading in the right direction, and we will continue to make cars with a more dynamic character right across our range – from small city cars, through to sports cars and luxury vehicles."

It was precisely this attitude to which the jury responded so emphatically, with Gene Lukianov noting, "A dynamics team led by a keen racer will naturally have some of his enthusiasm and dedication rub off on it and onto the rest of the corporation. Vehicle dynamics is more than engineering and art; it is also a sport."

DYNAMICS TEAM OF THE YEAR

Winner
Toyota
Highly Commended
Mazda
Also shortlisted
GM Korea
Hyundai-Kia

John Heinricy, principal, Heinrocket Inc
The winner of the 2008 *VDI* Dynamicist of the Year Award, Heinricy then took early retirement from GM and now runs Heinrocket Inc, focusing on vehicle testing and development, and high-performance driver training.

Graham Johnson, managing director, UKIP Media & Events Ltd
Johnson was the launch editor of *Vehicle Dynamics International* in 2003 and continued to lead the magazine until mid-2005, when he became managing director of UKIP Media & Events Ltd, *VDI*'s publisher.

Matt Joy, motoring editor, Press Association, UK
A respected road tester and occasional amateur racer, Joy drives just about every vehicle that hits the European car market and writes about them for PA's numerous high-profile outlets, including *Yahoo*.

Gene Lukianov, freelance engineer, USA
Former Chrysler dynamicist Lukianov is now a freelance dynamics consultant (via his VRAD Engineering business), amateur race car engineer and driver, and occasional technical writer with huge enthusiasm for all forms of engineering.

John Miles, vehicle dynamicist and journalist
Miles has more than 40 years' experience in the auto industry and currently works part time for Multimatic. He continues to share his wisdom with the readers of *Vehicle Dynamics International*.

Dynamicist of the Year

The admirable Subaru BRZ/Toyota GT86 combo has secured more honors for its creators, this time with a joint win in the sought-after Dynamicist of the Year category for Toshio Masuda of Subaru (*right*) and Tetsuya Tada from Toyota.

"It's back to the future for Mr Tada and Mr Masuda, creating the new generation of affordable rear-wheel-drive coupes," said jury member and noted performance car dynamicist, Peter Cambridge. Journalist Matt Joy added: "By sticking to a tried-and-tested formula, Tada and Masuda have created a car that enthusiasts

have been crying out for; one that eschews the never-ending quest for ultimate grip in favor of balance, response, and driving pleasure at realistic road speeds."

"The Subaru BRZ's development was not only a challenge, but served as a motivational boost for Subaru's engineers," said co-winner Masuda. "I would like to thank the jury and share the honor with all the engineers involved in the project."

"I have greatly enjoyed working with Masuda-san on this project," added his Toyota counterpart, Tada (*pictured above*), "and I believe that we have accomplished our key goal: to bring back the simple joy of driving. Personally, I look forward to meeting with GT86 drivers, to listen to their experiences, and to continue to develop even more exciting, dynamic Toyota cars for the foreseeable future."

DYNAMICIST OF THE YEAR

Winners
Toshio Masuda, Subaru/ Tetsuya Tada, Toyota
Highly Commended
Marcus Turner, Land Rover
Also shortlisted
Olaf Kwasny, Volkswagen
Tadanobu Yamamoto, Mazda

Development Tool of the Year

VI-Grade and its project partners have pulled out all the stops with this innovative new simulator, a fact not lost on the expert jury, which awarded the VI-DriveSim Dynamic technology a clear win over its fellow finalists in the Development Tool of the Year category.

"If Human and Hardware in the Loop engineering analysis can be fully embraced within existing vehicle development processes, then the template put forth by VI-DriveSim will prove to be a game changer," noted vehicle dynamicist Phil Morse. "The underlying beauty is that the key elements, each excellent in its own right, are effectively modular: Ansible Motion's kinematic motion platform and cueing, VI-Grade's vehicle physics and graphics, Multimatic's human interfacing, and so on. The synthesis of these elements into a functional whole serves as a model for the entire industry, embodying the spirit of globalization and cross-disciplinary cooperation."

"We are extremely honored to receive the award from a renowned institution like the *Vehicle Dynamics International* magazine," said Diego Minen, international technical director, VI-Grade. "This award proves the value of our development efforts over the past three years in putting together a complete turnkey solution for a driving simulator completely synchronized with engineering simulation. It confirms once again that driving simulators are becoming instrumental for the development of modern vehicles – passenger as well as racing cars. We would like to thank our partners Ansible Motion, Concurrent, Multimatic and SimCoVR for their valued support in the realization of the VI-DriveSim Dynamic solution."

DEVELOPMENT TOOL OF THE YEAR

Winner
VI-DriveSim Dynamic simulator – Multimatic/VI-Grade/ Ansible Motion
Highly Commended
WheelWatch – AICON 3D
Also shortlisted
Steering rig – Porsche/ University of Munich
Suspension Tester – ZF Test Systems

HOW IT WORKS

The *VDI* editorial team draws up a shortlist of finalists for the full jury to score. This year's panel is our biggest and most prestigious ever. Once everybody had cast their votes, we added up the points to determine the winner and a Highly Commended runner-up in each category.

If you feel your product, technology or achievement is worthy of recognition, be sure to tell us about it! Then perhaps this time next year, one of our trophies could be sitting on your desk.

THE JURY (continued)

Phil Morse, vehicle dynamicist and writer, USA
Morse has worked with a number of OEMs, as well as for open-wheel, stock-car, and sportscar racing teams. He now runs the Energy Balance consultancy based in Concord, North Carolina, USA, and is an occasional contributor to *VDI*.

Jonas Näfver, manager, automotive R&D, racing & rally, Öhlins, Sweden
A noted race engineer who won the Scandinavian Touring Car Championship with Rickard Rydell in 2011, Näfver also contributes when commitments allow to *VDI* and sister title *Professional Motorsport World*.

Simon Newton, lead engineer for chassis systems development, Williams Advanced Engineering, UK
Newton's remit includes integrating and optimizing all of the technologies, active and passive, relevant to the vehicle dynamics of the consultancy's high-performance vehicle programs.

Alvaro Sauras, technical editor, *Car&Tecno*, Spain
An engineer by training, Sauras has been technical chief of the Spanish Luike group's car magazines since 2007, including the technically minded *CAR&Tecno*, and *Autofácil*, which is Spain's best-selling monthly car title.

Jürgen Zöllter, freelance writer, Germany
"I have the best job on Earth!" says Zöllter, who contributes articles to more than 30 publications, including German titles *Focus*, *Welt am Sonntag*, *Autobild*, and *Autozeitung*, and *Car & Driver* in the USA.

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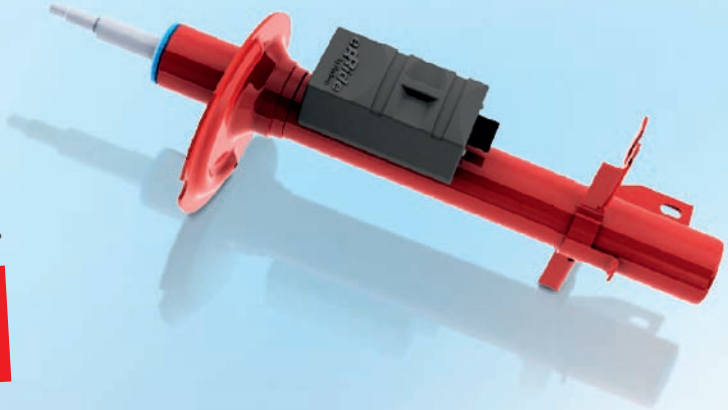

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Second coming

VDI INVESTIGATES LEADING AFTERMARKET CHASSIS OPERATIONS. **PETER CAMBRIDGE** RECOUNTS A NEW PROJECT FOR MOUNTUNE, AND IN *GOLDEN OLDIES* **MIKE MAGDA** EXPLORES AN INDUSTRY THAT BRINGS 21ST-CENTURY HANDLING TO US CLASSICS

The aftermarket tuning industry has often been regarded as the 'dark side' of automotive engineering. There are many companies producing suspension-related products that lower the car, reduce the roll, and make it firmer. Anyone can buy these parts, combine them with others, and then fit them to their vehicles with the expectation that the end result is, for them, going to be better than standard; a standard that has been developed by teams of talented engineers to be safe, to work on a variety of roads in all weathers and all load conditions, and to appeal, in its driving manners, to a wide customer base. Will it corner better? Does it look better? Is it safe? There are no guarantees other than the reputation of the companies and now the opinions of self-proclaimed experts on the many forums. It is an exciting but difficult market for a company to enter.

Mountune, the performance engineering division of Revolve Technologies, is established as a premier tuner of Ford cars in the UK, and is rapidly expanding into Europe. It is the only company to offer Ford-approved performance upgrades through the dealer network and works with Ford to produce special editions such as the RS500. To complement the engine performance upgrades and to offer customers a complete performance package, Mountune has been developing a range of products including wheels and tires, brake upgrades, and styling components. To complete the range for the Focus RS, a suspension package was required.

The Focus RS is a brilliant performance car. The ride and handling have been tuned to make an exciting and involving car that is practical enough to be used daily and whose dynamic character perfectly

Background

Peter Cambridge, the ex-Prodrive development engineer responsible for engineering the Subaru UK limited edition vehicles, as well as the Mazda RX-8 PZ and Alfa Romeo Brera S, has been working with Mountune on the vehicle dynamics of its Ford RS Focus to produce an upgraded suspension kit for the track-day customer.

MOUNTUNE FORD FOCUS RS CLUBSPORT SUSPENSION KIT (LEFT), **AND THE FINISHED PRODUCT** (MAIN IMAGE)

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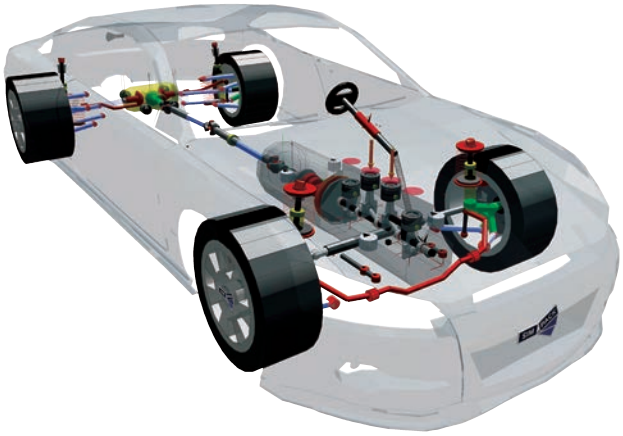
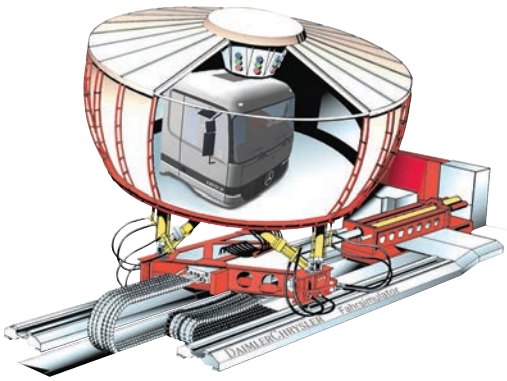
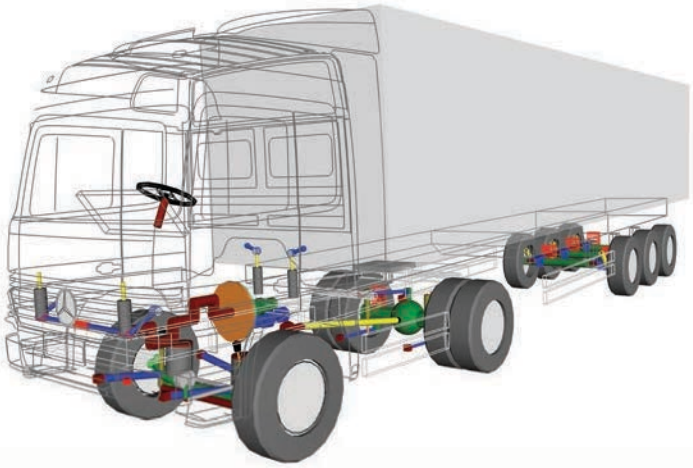
for Technology Leaders

SIMPACK Automotive







SIMPACK Multi-Body Simulation Software

SIMPACK is a general-purpose 3D multi-body simulation (MBS) software tool which is used to aid the development of any mechanical or mechatronic device, ranging from single components through to complete systems, e.g. passenger cars, high performance Formula 1 engines, railway vehicles and wind turbines. All SIMPACK products are 100% compatible.

SIMPACK Automotive is an add-on module tailored to the specific requirements of the automotive sector. It is uniquely suited to the analysis and design of any type of on- or off-road vehicles. SIMPACK Automotive is one of the leading MBS tools for commercial vehicles and is continually gaining ground in all other automotive sectors.

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matches the aggressive looks. Mountune wanted to focus the handling for a select group of owners who take part in track days and also run their cars on the road – hence the Clubsport name.

The project was run like a mini OEM vehicle refresh program – research the market, define the objectives, plan the program, manufacture prototypes, engineer the car, sign it off, and produce the production parts. The big benefit we had was that the vehicle was already fully signed off and so would not be changing during the tuning phase – as is always the case with new vehicles – and we were setting the dynamic targets.

Our research, using magazine reviews, discussions with well-respected journalists, and our own experience in tuning a range of high-performance road cars, yielded a clear competitor vehicle and a number of areas that could be enhanced. The Mégane Renaultsport was regarded by many as being the best road car for the track, with a dynamic character that gave the driver confidence at high speed, but retained the necessary agility. The RS just required tightening up for the track with a slight change in its steady state balance and a small reduction in the throttle adjustability.

The aftermarket is dominated by cost, like the OE side, and providing a kit to enhance a vehicle must offer value for money to the end customer. This limits the scope of the tuning parts and also dictates the supplier selection. I have a great deal of experience working with Eibach and Bilstein on limited-edition vehicles. The components used in the dampers are the same ones used in the OE parts and the shim stacks are built within guidelines created from the millions of cycles of testing of production dampers. The springs are specified by us but designed and manufactured by Eibach to their OE standards – good for engineering quality and marketing appeal.

The suspension tune followed conventional industry practice, with

"The Mégane Renaultsport was regarded by many as being the best road car for the track"

Golden oldies

According to the Specialty Equipment Market Association (SEMA), US consumers spent nearly US$10 billion on aftermarket suspension and handling products for their vehicles in 2010. While that number includes performance wheels and tires, it also encompasses shocks, springs, bushings, brakes, and other chassis components for the different niche groups tracked by SEMA.

Aftermarket suspension development in the USA is clearly split into three camps: upgrading late-model vehicles, 'restifying' popular vintage vehicles, and modifying pickups and utility vehicles for both show and off-road performance.

Truck owners are the most aggressive in addressing suspension issues, but a significant piece of that market is interested only in appearance and image by emulating monster trucks and desert racers.

With today's sophisticated suspensions, auto makers leave little room for improvement in late-model performance cars. High-end adjustable shocks, usually developed by racing companies like Penske Shocks and Pfadt Race Engineering, are making the biggest headlines, although there is still strong demand for basic upgrades, so cars can be more competitive in weekend track days or at an autocross.

Making a classic car handle perform like a modern sports car is perhaps the most challenging trend in the aftermarket today. Specialty suspension companies are completely redesigning the frames and suspension components of cars from the 1950s, 60s, and 70s. Modifying the engines had always been easy for classic car enthusiasts, but only recently have aftermarket suspension companies made a serious engineering effort to correct all the handling problems that handicap older cars.

"It really starts with the tires," explains Kyle Tucker, who started Detroit Speed with wife Stacy (both are mechanical engineers with OEM and racing backgrounds). "Now that we have modern tires, we can get into the vehicle dynamics and get more aggressive with camber curve, spring rates, and shock curve – both static and dynamic."

In a methodical approach, Detroit Speed uses a ROMER coordinate measuring arm to map out a vehicle's dimensions and analyze the stock suspension geometry. The engineers then use Solid Works and WinGeo3 suspension geometry software to design new suspension components, including tubular control arms to replace stamped units and multilink rear suspensions to replace leaf-spring setups. Detroit Speed also designs complete subframe replacements with new suspension geometry and coil-over conversions.

Detroit Speed outsources stamping, forging, and hydroforming operations, but handles all other fabrications and assemblies in-house. Shock absorbers are built by Sprint Cup supplier JRi Shocks to Detroit Speed's specifications, then tuned by Detroit Speed.

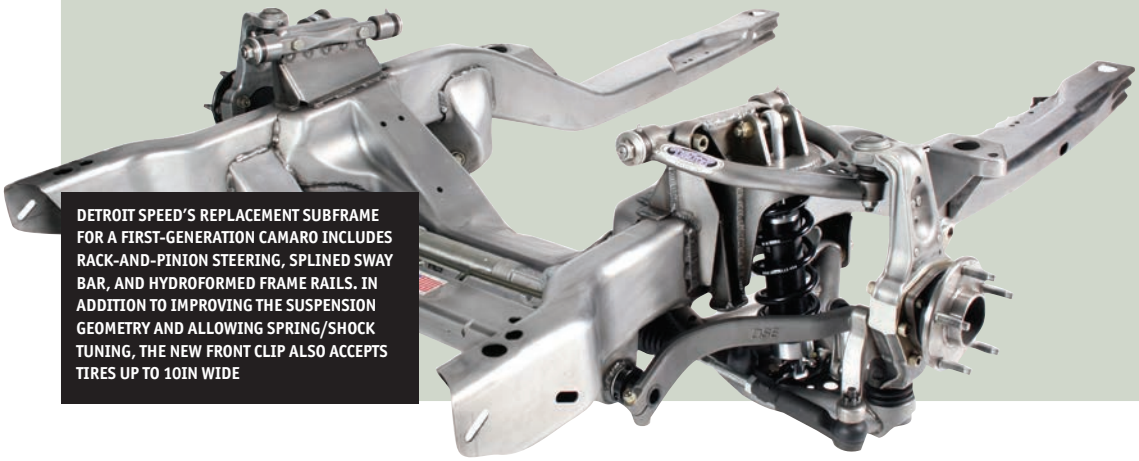
Meanwhile, Art Morrison builds replacement frames with updated suspension geometry, coil-over shocks, and fitment for wider tires. His most popular frame bolts up to 1955-1957 Chevy bodies with no modification, and will pull up to 0.94*g* on the skid pad. An Art Morrison replacement chassis for a 1953-1962 Corvette will go to 1.05*g*.

"We also give them a ride soft enough that it doesn't feel like you're riding in a [Nissan] GT-R," quips Morrison.

Two full-time engineers at Morrison measure stock vehicles with a FaroArm, then use AutoCad, WinGeo3, and SolidWorks to design new frames and suspension parts.

"It allows us to do all the 'what ifs' before we go to the shop," says Morrison, who started out by developing drag racing chassis in the 1970s.

Morrison will also develop a full-frame chassis for a unibody car. A recent project mated a new Nissan Cube body with a Morrison chassis that supported a 600bhp, 6.2-liter Chevy LS9 supercharged V8 engine.



DETROIT SPEED'S REPLACEMENT SUBFRAME FOR A FIRST-GENERATION CAMARO INCLUDES RACK-AND-PINION STEERING, SPLINED SWAY BAR, AND HYDROFORMED FRAME RAILS. IN ADDITION TO IMPROVING THE SUSPENSION GEOMETRY AND ALLOWING SPRING/SHOCK TUNING, THE NEW FRONT CLIP ALSO ACCEPTS TIRES UP TO 10IN WIDE

New metal from the German tuning giants

COMPILED BY JOHN O'BRIEN

ABT Sportsline AS6

The renowned Volkswagen Group fettler has offered up its vision of the Audi A6 Avant. The load-lugger gets a significant power hike to over 540Nm of torque in the TFSI model, while the bi-turbo diesel now pumps out 700Nm. Ensuring that this is transferred effectively, ABT has fitted 30mm-shorter springs as well as a choice of obligatory oversized alloys, available in 19-, 20- or 21in fitments.

Brabus Bullit 800

The Mercedes specialist's latest creation is the frankly bonkers 800bhp, 1,420Nm-producing Bullit 800 coupe. Beneath the skin of the C-Class coupe body, are a custom, Brabus-reinforced LSD and gas-pressure, height-adjustable coilovers, developed in cooperation with Bilstein, Brabus's technology partner. Number 11s can be left on the tarmac through a choice of Continental, Pirelli or Yokohama 275/25 R20 tires.

Gemballa Tornado

Based on the Porsche Cayenne, the wide-bodied Tornado SUV uses carbon panels to shave more than 70kg from the factory car. 'Stage one' engine mods see power raised to 580bhp, while the latest 'stage two' package will bring 700bhp and 1,000Nm. Keeping this craziness in check are Brembo-sourced 420mm discs and six-pot calipers – hidden behind 22in wheels, wrapped in 335/30 R22 rubber bands.

"The initial phase of the tuning produced a car that felt like the natural evolution of the RS. With the higher ride frequencies, the car felt smaller and lighter"

spring rates being selected to give the desired ride frequencies and pitch behavior. The ride heights, spring aid rates, and contact points were all set to provide the steady state balance and basic ride characteristics we desired. Changing the ride height affects the roll centers and position on the bump steer curves, and these were considered. Altering any of the kinematic and compliance characteristics is not within the scope of a small project like this. Only optimization of the static geometry settings, to suit the new suspension tune, can be achieved.

The dampers were tuned on the road and checked on the track. The random nature of our British roads, especially in Warwickshire, provides ideal input for choosing the settings. Some projects I have worked on in the past have required the damping rates to be started from scratch to achieve the desired characteristics, but the RS was different. The standard damper rates are a superb compromise, giving a fine balance of comfort and handling (described as "playful" by one journalist), that we effectively copied into a tuneable shim stack to use as our starting point.

The initial phase of the tuning produced a car that felt like the natural evolution of the RS. With the higher ride frequencies, the car felt smaller and lighter. The body control was very tight – for a road car – giving the impression of there being no roll. Traction and stability were good, but aspects of the ride would require improvement.

Mat Jackson, the British touring car driver, has links with Mountune. He assessed the car at the Bedford Autodrome, before the damper tune was finalized to give a racer's view of the track performance and to set a lap time. It is quite possible to create a tune that feels very sporty, but is actually slower than the standard one around a track. The car was quick, setting lap times faster than some more exotic machinery, but a little more control was necessary. Feedback like this is invaluable when producing a tune aimed at track use.

The final phase of the tuning focused on improving the ride and adding a little more body control. More compliance and high-speed control was created by changes to the damper shim stacks. The static geometry was then optimized, within the standard Ford tolerances, to provide the best initial steering response and feel to match the revised character. The final suspension specification was signed off through testing in high- and low-μ conditions in the two-up and fully laden conditions.

The production parts have now been produced and the first batch of kits are with customers. The feedback so far has been extremely positive. Mountune has entered the suspension-tuning market with a product engineered to complement its current range of tuning packages and to build on the dynamic performance of the standard RS.

Ahead of the Curve

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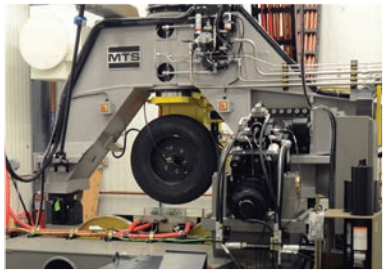

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Right on track

McLAREN AUTOMOTIVE'S HEAD OF VEHICLE DYNAMICS, **PAUL BURNHAM**, EXPLAINS WHY HE BELIEVES FORMULA 1 TECHNOLOGY CAN MAKE ROAD CARS BETTER TO DRIVE

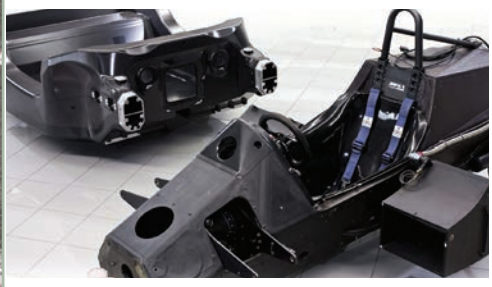
Any Formula 1 race engineer will tell you what makes a car fast on track: good braking and corner-entry stability, neutral mid-corner balance, and good corner-exit traction. Instability is generally bad, except in the case where the driver can deliberately exploit slow-yaw-rate slides to get the car turned, but he ultimately needs to be able to lean on the car with confidence.

For a road car at the highest level of the market, these same traits are important. And for a McLaren, the target is a similar quality of track performance as that of a race car. However, to achieve this without compromising comfort or usability, it is necessary to deploy the full range of technologies available.

Other race car requirements that translate directly to road cars are low weight, low center-of-gravity height, and low yaw inertia; all of which necessitate clever packaging, as well as the use of modern technologies such as carbon fiber and other advanced materials.

Modern cars are frequently compromised by cost considerations. One example of this is the extent to which family hatchbacks often rely on ESC systems to give acceptable stability. While there clearly are cost constraints in the super-sports car sector, these compromises are not acceptable for McLaren. The aim is to make the car as good as possible through mechanical design and effective use of (mechanical) technology. Then the addition of electronic systems can be used to further improve the performance, rather than paper over the cracks of

Transfer windows



Formula 1 cars are famous for employing the latest performance technology. Close analysis shows that there is a strong record of technology developments in F1 making their way down through high-end road cars, and eventually to mass-market vehicles.

Perhaps the most significant example is the manufacturing of carbon-fiber body structures, a concept that McLaren introduced to Formula 1 in 1981 with the MP4/1 monocoque chassis. A carbon-fiber chassis was then developed for the first time in a road car with the McLaren F1, in 1992 (106 road and race cars produced), and then followed the Mercedes SLR McLaren (2,153 cars built from 2003-2010). Now McLaren has launched the MP4-12C, which features a one-piece-molded, carbon 'MonoCell' chassis, and for which production volumes could surpass 1,500 units in each year of its life.

The close links between McLaren Racing and McLaren Automotive mean technology transfer is a very real prospect. In this way, ideas that have found their way onto the Formula 1 car, and many which could never be raced in Formula 1, can be used on road cars with few limitations – as long as a business case can be made. In Formula 1 these systems are not simply marketing assets, but genuine performance-enhancing technologies, so for a company like McLaren it is generally not too difficult to make a business case.

Possibly the greatest influence Formula 1 has had in manufacturing road cars is the transfer of the attitude of personnel who have developed their skillsets with a racing mentality. McLaren Automotive is fortunate to employ many people who have transferred from the Racing division, and the benefit of having people used to working with extreme efficiency is tangible.

poor design, and to ensure that the car becomes a realistic proposition as an everyday vehicle. A 600PS lightweight sports car without traction control would not be an everyday car for an untrained driver.

At McLaren, stability control system modules are considered in two ways. Some, such as anti-lock braking systems (ABS) are beneficial whether the driver is professional or amateur – they enhance the performance of the car and so will be engaged at all times – even in 'ESC Off' mode. Others, such as oversteer yaw control, are safety systems that expert drivers might consider intrusive – therefore these have variable thresholds depending on the selected driver mode.

A major part of the McLaren philosophy is not to copy the rest of the market, but to engage in a thorough debate about the merits of each system and decide what best meets the performance targets. On the subject of differentials, for example, a limited slip differential (LSD) clearly has one main aim – to improve traction by preventing the uncontrolled spinning of the inside wheel. But using an LSD incurs penalties for the driver of increased NVH, component weight, and understeer.

A locking differential is a feature that will be used rarely by customers of an everyday car, so if you could find a system that provides all the advantages of a torque-vectoring differential in the rare occasions when it is used, but adds none of the disadvantages listed above and saves tens of kilos in the process, then it would be tempting… and this is what 'Brake Steer' provides.

Brake Steer

Brake Steer is a system that started life on the racetrack – it was used in Formula 1 on the McLaren MP4/12 and MP4/13 in 1997 and 1998. In the Formula 1 car, it was manually activated by the driver using a third pedal (*see picture overleaf*), but in the 12C it is not practical to require drivers to do this job themselves.

Happily it is now possible to use the existing ABS pump to do the job, but during the 12C's development, a considerable amount of effort was expended to ensure that the Brake Steer torques were introduced at the right time to give maximum performance, while feeling intuitive and transparent to the driver. Simulations and tests in the driving simulator had shown that the system would be effective at providing a significant laptime performance benefit compared with a conventional LSD, so a prototype system was built for a mule car.

The initial experiments on the mule car did use a manually activated hand pedal, which acted only on right-hand corners, and this proved that it was possible to achieve the predicted gains. Looking at the data for where a professional driver used the manual system – and how aggressively it may be operated – also guided the initial algorithm development.

"During development of the Brake Steer deployment algorithm, it was found that different drivers could provoke very different responses to the system"

CROSS-SECTION OF A McLAREN PCC/TENNECO KINETIC DAMPER

THE THIRD PEDAL TO OPERATE BRAKE STEER IS SHOWN IN THIS PHOTO OF A McLAREN F1 CAR OF THE LATE 1990s

However, during development of the Brake Steer deployment algorithm, it was found that different drivers could provoke very different responses to the system – drivers who 'saw' at the steering wheel would get a very different feel to smooth drivers. Also, the way the Brake Steer torque was introduced and released on corner entry and exit were critical to achieving a satisfactory system feel. The aim was to make the system feel like the car naturally has huge grip and traction, and in the production system it is almost transparent to the driver.

While employing Brake Steer does increase the energy input to the rear brake pads, a large variety of testing has shown that the rear pad wear is no worse than the front pad wear, since typically without Brake Steer the front pads would wear faster than those at the rear.

ProActive Chassis Control

A feature of super-sports cars in the past 20 years has been poor ride comfort. Firm springs and damping rates achieve optimum body control, and since the requirements for this sector generally include excellent handling, ride comfort has been the loser. The result has been cars less suitable for everyday use where a reasonable level of compliance makes a huge difference to the ownership experience. Even on track, the ability to ride bumps and curbs easily can result in significant laptime benefits.

For this reason, ride comfort is a priority for a McLaren sports car – the intention is always that the car should be an everyday proposition – and to achieve both excellent ride and handling performance requires the use of the best technologies. The 12C is the starting point in a range of cars, and in future McLaren cars ride quality will always be as good as possible, while achieving the required handling characteristics.

Feedback from early 12C owners indicates they are delighted by the combination of comfort and agility provided by the car's ProActive Chassis Control (PCC) system.

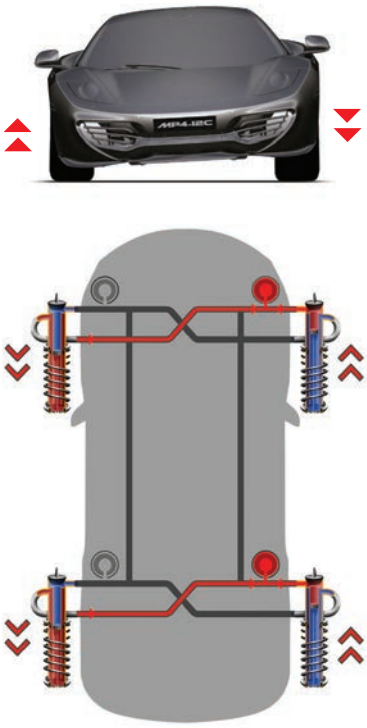
As you might expect for a company that employs some of the finest racing drivers in the world, at McLaren it is also considered crucial to use the best drivers for developing road cars. McLaren believes this is necessary because the best engineers may not be the best drivers – and to build the best cars you need both. While being a racing driver is not a prerequisite to being an excellent test driver, McLaren believes that racing tends to provide excellent experience in putting a car absolutely on the limit, while maintaining enough mental capacity to analyze what is going on with the suspension and tires.

Most car enthusiasts could probably explain what pitch and roll are, and some are aware of the technical term 'heave', but few have been aware of the term 'warp' in the past. Warp, being the opposing roll of front and rear axles ('chassis twist' if you like) normally has a stiffness that is a by-product of whatever roll stiffness a car has, since it is not an independent mode. However, while warp inputs are not strongly related to handling criteria, they are extremely relevant to comfort over non-smooth surfaces, so an ability to remain compliant for this mode can have significant comfort benefits with no loss of handling performance.

For the suspension system to be able to discriminate between roll inputs (front and rear roll in-phase) and warp inputs (front and rear roll out-of-phase), it is necessary to have a connection of some sort between front and rear axles. In the 12C this is achieved with hydraulic lines, and the hydraulic layout naturally results in near-zero warp stiffness, along with a much higher (and variable) roll stiffness. In addition to excellent ride quality, the PCC system provides very consistent handling balance on bumpy corners as the roll moment distribution is largely unaffected by input from the road surface. Straight line and corner exit traction is also very good due to the relatively low wheel rates on the rear axle.

An additional benefit of this system is that it is able to adjust roll stiffness between different driver-selected modes by varying the static hydraulic pressure, which is clearly more difficult with mechanical springs.

The MP4-12C's PCC suspension system is in fact two systems – a passive anti-roll system (which also has low warp stiffness) combined with a semi-active (adaptive) damping system. The damping is electronically controlled with continuous sensor measurements and a real-time processor calculating the required damper forces, but the anti-roll system is passive apart



UNDER ROLL CONDITIONS IN THE MP4-12C, THE FLUID FROM OPPOSING DAMPERS 'COLLIDES' ACROSS AN AXLE AND IS FORCED INTO THE ACCUMULATOR, COMPRESSING THE GAS AND CREATING GREATER ROLL STIFFNESS DEPENDENT ON THE PRESET PRESSURE WITHIN THE SYSTEM

from occasional corrections to the system's hydraulic pressure. These pressure corrections are required in response to temperature changes or the driver changing 'chassis mode' in the car. If a pressure correction is required, then the PAS pump is used to pressurize the system to the new pressure, but once the valves are closed, the system operates passively again.

The system pressure cannot be altered while cornering since the anti-roll system relies on a pressure delta between two circuits to resist roll, so adjusting pressure while cornering would result in loss of roll stiffness. However, this also means that it is possible to share the PAS pump between steering and suspension, because when driving in a straight line there is no requirement for steering assistance.

The application of systems such as PCC show that the technology and mentality of Formula 1 can deliver tangible benefits to road cars. This is already the case for the MP4-12C, but given the rate of adoption of some of these technologies, it will not be long before the benefits are also felt in other market sectors.

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VOLKER STRYCEK,
MANAGER,
OPEL PERFORMANCE CENTER

There's probably no bigger marketing cliché when it comes to performance cars than the racetrack 'improving the breed'. All too often, there's no engineering crossover whatsoever between a company's roadgoing vehicles and its competition cars.

But that's not a charge that could be leveled at Opel Performance Center (OPC), which turns out OPC-badged Opels and VXR-branded Vauxhalls for GM Europe. That's perhaps no surprise given that the man at the helm of the Rüsselsheim, Germany-based operation is former DTM-winning driver and Nürburgring guru, Volker Strycek.

When Opel launched the Insignia OPC back in 2010, its HiPerStrut front suspension was used in the class SP3T Astra OPCs that Kissling Motorsport built with OPC for that year's VLN and Nürburgring 24 Hours. Also forged through OPC's racing tie-up with Kissling is a relationship with Drexler Motorsport, whose limited-slip differential is now fitted to the two most recent OPC road cars – the

Sport for all

VOLKER STRYCEK'S OPC DEPARTMENT USES RACETRACK-PROVEN PARTS TO TURN REGULAR OPELS INTO PERFORMANCE SPECIALS. INTERVIEW BY **GRAHAM HEEPS**

Corsa OPC Nürburgring Edition, and the just-launched, new-generation Astra OPC three-door coupe (see panel overleaf).

"The group is split between motorsport and OPC road cars, but we work together, so all the knowledge from the road-car group is transferred to motorsport, and vice-versa," says Strycek. "In the past we've had a lot of standard road-car parts in the race cars. We know then that they are proved on the Nordschleife under much more stressful conditions than they would otherwise be on the race car. So we really can talk about synergies between road and track."

That's not to say that the 28-strong OPC team are a bunch of petrolheads who'll blithely strap a motorsport part onto a road car. Quite the opposite, in fact: Strycek is very conscious of the different demands of road and track, and the need for usable performance in the hands of the many, rather than speed that can only be unlocked by the talented few.

"The driver must be in charge at all times, not the car," he explains, noting the torquesteer that has marred certain LSD-equipped FWD cars in the past. "Sometimes an LSD can be dangerous and that was the reason why we had never before had one in a FWD car. Traditionally it can be very difficult to handle, especially in low-grip conditions.

"But in the Astra we're running a mechanical multi-plate LSD that's very intelligent. The differential creates its locking effect with a ramp angle of 45° under acceleration and 90° under deceleration. That's what makes the differential so smooth. You have a limited-slip that you only feel in terms of acceleration and traction, not in the steering system, because it comes in smoothly rather than suddenly. We have a preload of 40N, which means that everything is in place to react very quickly, but you don't feel it as a driver."

The LSDs for the Corsa Nürburgring and Astra OPC represent Drexler's first-ever road-car programs, and were developed pretty much in parallel. Strycek says that they share many similarities, with the obvious exception of being paired with different gearboxes: the M32 in the Corsa, the F40 in the Astra.

The diffs represent the latest in a line of OPC developments that have been applied to more than one product. In addition to the torquesteer-reducing HiPerStrut, which has migrated from the Insignia down to the Astra, there's also a Brembo brake package featuring motorsport-style co-cast iron/aluminum floating discs that has also stepped down a class to the new coupe. But that's not to say that Strycek takes a one-size-fits-all approach to speccing his cars.

"We are very close to our customers," he insists. "Their backgrounds vary from car to car, so a Corsa needs to be set up completely differently from an Insignia, which might be used by a family. Also, the market split varies a lot from car to car: in the compact class, we have a huge proportion of our sales in the UK with the VXR, but we see a much more equal distribution throughout Europe for the Corsa, for example."

Particularly since the introduction of the Sachs CDC-based 'FlexRide'

> **"Traditionally a limited-slip differential can be very difficult to handle, especially in low-grip conditions"**
> Volker Strycek, OPC

LEFT: **INSIGNIA OPC WITH ROLF LORENZ, OPC MECHANIC (LEFT) AND VOLKER STRYCEK.** ABOVE: **ASTRA OPC'S LIGHTER ALLOY WHEEL**

"We finish all our developments with a 10,000km run on the Nordschleife. If we get failures, we start again"

chassis, OPC products have no longer had different setups for different markets. The scenario whereby the original Astra VXR was co-developed with Lotus Engineering and differed to the OPC version sold on the European mainland has not been repeated. But Strycek's team took the new model to Spain, Italy, Sweden, the UK, and France, "to bring everything together and find a good compromise between the needs and requirements of each country."

At the center of every OPC development, however, is the Nordschleife. It would be easy at this point to do Strycek and his team something of a disservice: Strycek is a VLN regular, a 24h winner, and an unapologetic fan of the legendary circuit. An obvious candidate for an unhealthy obsession with the 'Green Hell', then, rather than keeping the focus on real-world performance? Not so, he says.

"The Nordschleife is a proving ground," he asserts. "It's very bumpy, very twisty, you've everything there – tight corners, quick corners, right- and left-hand corners. You can develop ride comfort on the Nordschleife, agility, handling, brakes, everything – what works there seems to work everywhere. But round about it are a lot of public roads that have similar characteristics to, for example, UK roads, so we do a lot of mileage on them as well."

Every OPC development is rounded off with a 10,000km durability run on the Nordschleife, which is extrapolated by a factor of 18 to equate to a real-world 180,000km, which Strycek stresses is a harder test than the factor of 22 favored by some other OEMs. One senses that he wouldn't swap this final run for anything – and it delivers results. "For the Insignia, our colleagues in the laboratories did the normal durability tests, and everything was fine," he says. "But when we did the runs on the Nordschleife, the wheel hubs broke. The left side went after 9,300km, followed 200km later by the right. People said, it's not possible! But it showed us that you cannot simulate this kind of stress. That's why we finish all of our developments with the 10,000km run on the Nordschleife, and if we get any failures, we'll start again, and again, until we get no failures."

STRYCEK AND HIS COLLEAGUES TOOK THE ASTRA OPC TO ARJEPLOG IN LATE-MARCH TO FINALIZE THE ABS AND ESC SETTINGS ON SNOW AND ICE

The runs went better for the new Astra, with no failures recorded.

"We finished the 10,000km and wanted to do it all again, so nice was it to drive the car," Strycek smiles.

With a "pretty stable" team of engineers working on the products, Strycek can ensure that the learnings accrued over time get carried forward into the next project. The group currently has no major motorsport project on the go, but is supporting customers running Opels, for example the privateers competing for the Opel Performance Cup with its €100,000 (US$130,000) prize fund, or the diesel Astra GTCs that are currently cleaning up in the HJS Diesel Rallye Masters series.

OPC's work has also started to creep out of its European heartland, with the Insignia OPC's chassis forming the basis of the Buick Regal GS, although he's yet to take on a commission for a non-OPC car for elsewhere in GM.

"We are able to use synergies across the company, but we're not yet doing specific projects for other divisions. For the future, who knows? But we have enough work with our regular projects."

Not so much that he won't have time for the odd VLN race on the Nordschleife, though. Look out for the class SP3T Astra GTC, complete with HiPerStruts.

OPC's Scirocco-fighter

Volker Strycek describes the new Astra OPC/VXR, based on the three-door GTC model, as "another step forward" for his group.

"We have 280 horsepower and 400Nm between 2,450rpm and 5,700rpm. Our focus was therefore on bringing this power to the road, which is why we developed the mechanical limited-slip differential. The different ramp angles under acceleration and deceleration make the differential smoother – you can't feel it in the steering system, but particularly when you get on the throttle on the exit of a tight corner, you have an immediate response from the engine and a level of grip that isn't normal for a FWD car."

The GTC was benchmarked against the Mégane RenaultSport and the VW Scirocco R. To take the fight to this impressive pair, Strycek's team has given its car a HiPerStrut front suspension with an additional stiffness bar across the subframe to improve agility. A new rear axle has different torsion rates and fixing points, still based around the Watts link suspension of the standard car. And then there's the damping, which is done by a new generation of the familiar Sachs CDC system.

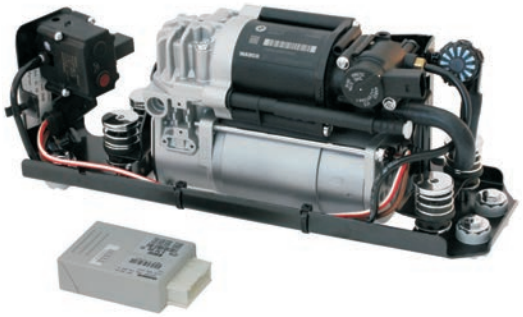
"At the Nordschleife there are a lot of crests," Strycek notes. "The dampers have a roll-rate sensor and a crest-rate sensor. If the damper is running in high-speed areas – more than 2m/s – then we already know before the car comes back down into the bump phase after a crest, and can react in milliseconds."

The feature is controlled by cabin switches: normal mode doesn't take account of the crest and roll-rate inputs; it's then approximately 30% active in Sport mode, and 100% in OPC mode.

Other areas that have received attention compared with the standard car are the Conti Teves ESC, the bespoke Pirelli tires, and the alloy wheel rim design. The latter looks similar to the Insignia OPC's, but thinner spokes contribute to an unsprung weight saving of 500g per wheel.

Air Suspension as Standard

it's a feature not an option!



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Resistance is futile

MAELLE DODU OF THE ADVANCED CHASSIS ENGINEERING DEPARTMENT AT JAGUAR LAND ROVER LOOKS AT TIRE REQUIREMENTS FOR LOW-CARBON VEHICLES

The biggest challenge currently facing the automotive industry is the development of new and more sustainable road mobility, the main aspect of which is the reduction of the environmental impact of road vehicles. In order to reach their targets in terms of energy savings, OEMs are having to develop low-carbon vehicles.

This obviously implies significant requirements on tires in terms of weight and drag reduction, in order to improve vehicle efficiency. This could mean a complete shift of focus onto rolling resistance and weight, but actually that is not the case. On the contrary, the tire is set to play an even more central role in the overall performance of low-carbon vehicles.

In order to develop low-carbon vehicles within a realistic and relevant timescale, OEMs have identified the key technologies required in a roadmap along with the key issues that the application of these technologies raises. This roadmap is shared by the OEMs, who recognize the same technical and commercial barriers. One example of this is the NAIGT roadmap established by the UK automotive industry in order to achieve the targets set for European Union CO_2 emissions cuts.

In terms of propulsion, the technologies identified are IC engine optimization, including downsizing and boosting, and the alternative systems – the hybrid vehicle, the electric vehicle, and the fuel cell vehicle. The other aspect to focus on when developing low-carbon vehicles, whatever the propulsion type, is improving vehicle energy efficiency and reducing parasitic losses.

Four main phenomena contribute to vehicle power loss – rolling resistance, internal friction, vehicle inertia, and air resistance – and depending on the vehicle's mode of operation, their relative importance differs. When driving around a city, with many acceleration/braking events, the vehicle inertia and rolling resistance are the main factors to be considered; whereas, at a stabilized highway speed, air resistance is the dominant factor by far, with rolling resistance being the second most important factor.

This means that in order to reduce the amount of wasted engine power,

RIGHT: **JAGUAR EXPECTS THE C-X75 HYBRID SUPERCAR TO PRODUCE CO_2 EMISSIONS OF LESS THAN 99G/KM CO_2, WHILE BEING ABLE TO ACHIEVE IN EXCESS OF 200MPH**

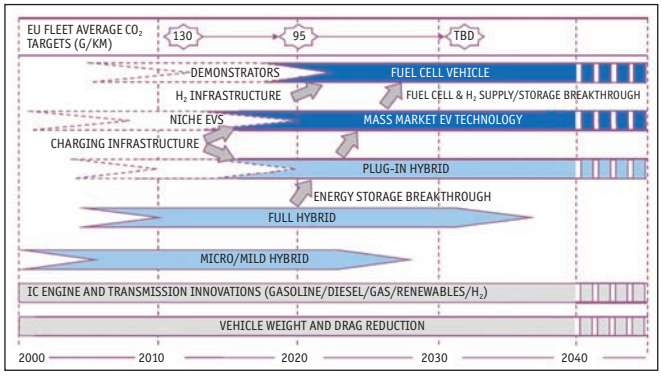
the efficiency of the powertrain and the vehicle must be improved, and the weight of the vehicle must be reduced. Improving powertrain efficiency is carried out via the design of more efficient electric motors, gearboxes, driveline, and APU. Improving vehicle efficiency means improving system integration and strategy, reducing aerodynamic drag, improving the efficiency of electrical systems such as power steering, and developing energy recovery and storage from systems such as the exhaust and the brakes. Reducing vehicle inertia is carried out via the development of lightweight solutions for all the vehicle components. This means using lightweight materials and reducing the quantity of materials used; but it also means designing components to fulfill their defined function – and no more – without over delivering.

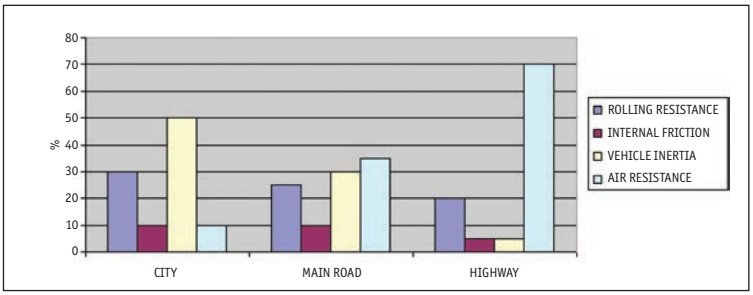
While the technology roadmap to low-carbon vehicles is shared by the car manufacturers, the application of the roadmap does not mean that, by 2020, all the car manufacturers will end up producing similar cars. Each of the OEMs will apply this roadmap in their own way, with their own timescales. This will depend on vehicle DNA, among other issues, and this is directly related to the market

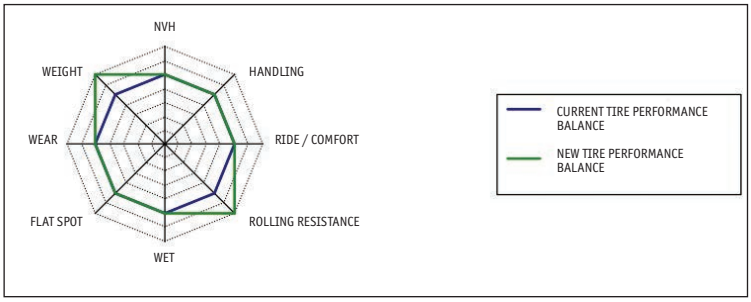
Evoque: a way forward

One way toward reaching the EU CO_2 emissions regulation targets for Land Rover was the introduction of the Range Rover Evoque in 2011. It is the smallest, lightest, and most fuel-efficient Range Rover ever. The most efficient version of the Evoque model range achieves 129g/km. In order to deliver lower CO_2 emissions, lightweight technologies have been used throughout the body and chassis. Front lower control arms and front/rear suspension knuckles are made of aluminum, which has helped save 12kg. The design of components such as the alloy wheels and the front subframe has also been optimized to reduce their weight. Innovative chassis technologies have been developed in order to eliminate energy inefficiencies and maximize fuel economy. EPS has been adopted instead of a hydraulic system and tires with optimized rolling resistance have been specially developed with the tire suppliers. For instance, the new 19in Continental tire, the 235/55R19 Conti CrossContact UHP-E, has a rolling resistance coefficient of less than 7.5kg/T, which corresponds to a 'B' in the new tire labeling standards.

THE RANGE ROVER EVOQUE IS THE SMALLEST, LIGHTEST, AND MOST FUEL-EFFICIENT RANGE ROVER EVER. IT'S PICTURED HERE ON BESPOKE 235/55R19 CONTI CROSSCONTACT UHP-E TIRES







CLOCKWISE FROM ABOVE: **LOW CARBON VEHICLE DEVELOPMENT ROADMAP (NAIGT); POWER LOSS BREAKDOWN; TIRE'S CENTRAL ROLE IN DEFINING VEHICLE PERFORMANCE**

positioning they have chosen for their products, as well as their brand aspirations.

Most customers want to be environmentally friendly but don't want to compromise on performance. In the case of Jaguar Land Rover (JLR), the company's objective for the years to come is to produce cars that are able to deliver low CO_2 emissions but, at the same time, still perform like a Jaguar or a Land Rover. This means maintaining the standards that customers expect when they buy JLR vehicles. The hallmarks are well defined: Jaguar means luxury sport saloon and sports cars that provide the customer with a high level of comfort, refinement, and a real driving experience; whereas Land Rover means premium 4x4 designed for performance and capability both on and off road.

This illustrates the challenge each OEM faces in developing low-carbon vehicles while continuing to meet brand aspirations. And in taking up this challenge, the tire industry has a critical role to play in terms of the tire's fundamental role in the definition of vehicle performance balance. The tire has a defining impact on almost all aspects of a vehicle's performance: from handling to rolling resistance, from weight to NVH, and – critically from a customer point of view – the tire's contribution to vehicle performance in the wet.

Consequently, the development of low-carbon vehicles has an impact on tire requirements on two levels. The first one is related to the tire's direct contribution to fuel economy and CO_2 emissions reduction. The wheels and tires represent an important part of the vehicle's resistance forces: 8% of vehicle inertia, 15% of air drag, and 100% of rolling resistance. A reduction of 10% in tire rolling resistance accounts for a fuel consumption reduction of 1.5-2%. So, tires need to be designed with reduced weight and rolling resistance, while maintaining other performance levels, and robustness.

The impact of low-carbon vehicles on tire requirements is also related to the specific characteristics of these new vehicles. The development of lightweight vehicles has an impact on the vehicle mass distribution and structure stiffness, which, in turn, have an impact on tire handling and NVH requirements. This also has a direct impact on requirements in terms of tire load capacity and wear. The development of alternative propulsion types with electric motors and batteries has an impact on mass distribution, with new packaging solutions needing to be considered, as well as wheel torque and vehicle noise levels. This means further impacts on tire handling and NVH requirements. Finally, with wheels and tires accounting for around 15% of air drag, improving aerodynamics in terms of tire width, sidewall, and tread pattern is also a consideration.

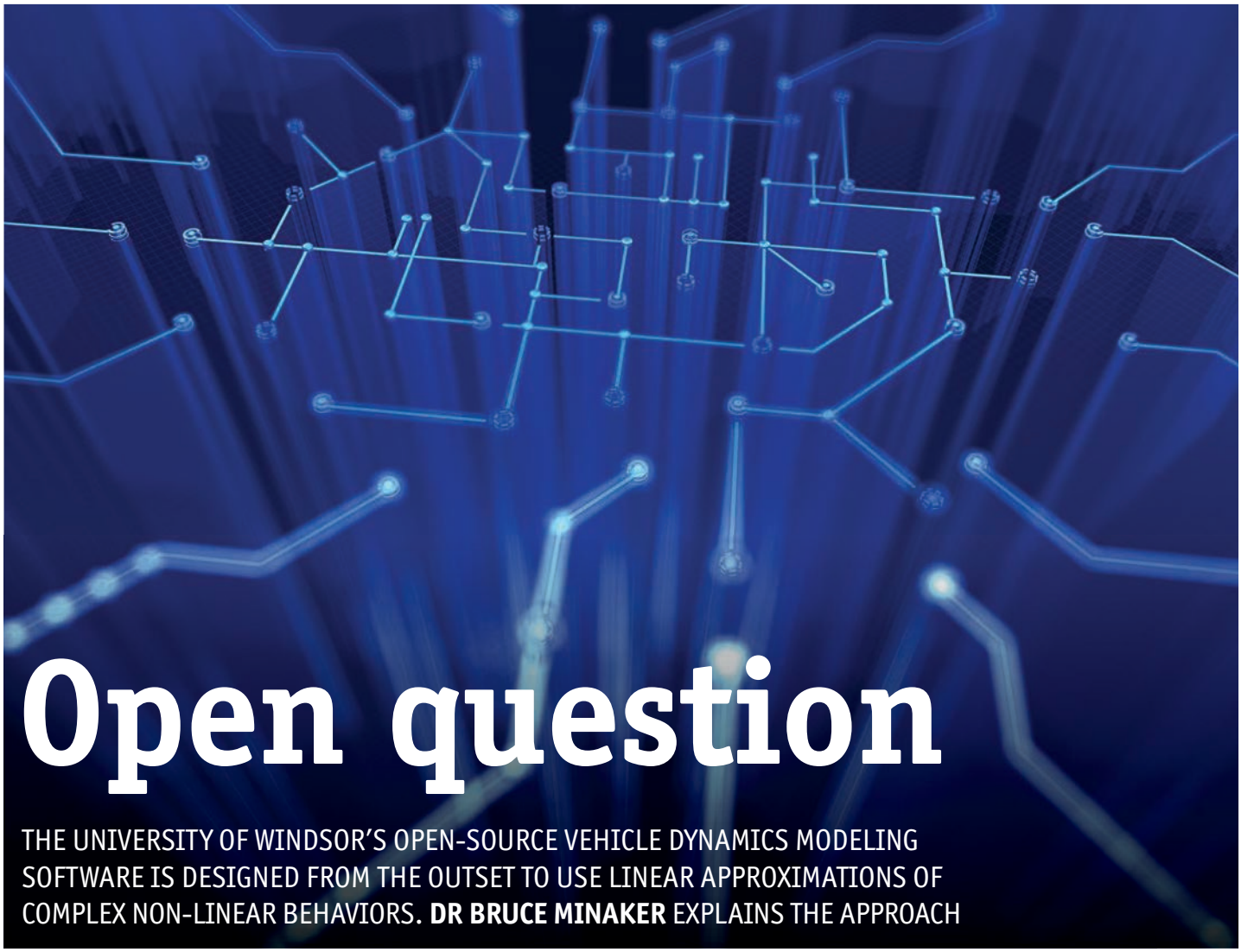
WHY LOW CARBON?

Tailpipe CO_2 emissions currently account for around 80% of a vehicle lifecycle carbon footprint. In the European Union (EU), passenger cars alone are responsible for around 12% of CO_2 emissions.

In this context, the pressure to reduce the CO_2 emissions of our vehicles comes first from the regulators. In the EU, the legislation that sets emissions performance standards for new passenger cars was adopted in 2009. It states that the target for the CO_2 emissions average of an OEM fleet should be 130g/km starting in 2012, when 65% of each manufacturer's cars newly registered in the EU must comply with this limit. From 2015 onward, this will apply to 100% of its fleet. If the average CO_2 emissions of a manufacturer's fleet exceeds this limit value, the manufacturer has to pay a penalty for each car registered of up to €95 for each g/km in excess. That means the fine can reach several million euros quite rapidly. And it does not end there; there is a long-term target already specified for 2020 of 95g/km. This is the legislation for the EU, but similar regulations are coming into force in other parts of the world, such as the USA and Japan.

The pressure also comes directly from the consumers, for whom fuel efficiency – and by implication, the cost of running the vehicle – is now considered a major factor when buying a car. And this concerns customers of every OEM, from the Renault Twingo buyer, to the Jaguar XJ buyer.

This leads us to the last reason to develop low-carbon vehicles: the economic one – the ever-rising oil costs and the fear over future supplies. More than 100 years ago, when the automotive industry and the internal combustion engine was born, fossil fuels were chosen over other propulsion systems because oil was cheap then and was considered to be an almost endless source of energy. Today, with the end of the oil age a few decades away, OEMs have to develop low-carbon vehicles with alternative propulsion systems, while improving vehicles' energy efficiency.



Open question

THE UNIVERSITY OF WINDSOR'S OPEN-SOURCE VEHICLE DYNAMICS MODELING SOFTWARE IS DESIGNED FROM THE OUTSET TO USE LINEAR APPROXIMATIONS OF COMPLEX NON-LINEAR BEHAVIORS. **DR BRUCE MINAKER** EXPLAINS THE APPROACH

The faculty and students in the Vehicle Dynamics and Control Research Group at the University of Windsor, Canada, have been developing a set of vehicle dynamics simulation codes for a number of years. The software is intended to be used by university-level engineering or computer science students, or practicing engineers with an interest in expanding their understanding of vehicle dynamics on a fundamental, theoretical level.

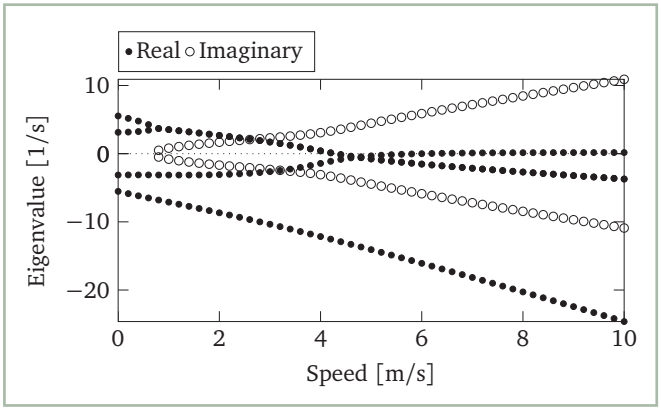
The group, led by the author, focuses on three principles with its vehicle modeling software. First, the code is free and open-source wherever possible, and published under a public license. This enables easy distribution, and promotes exposure to vehicle modeling and simulation, particularly among students. Second, the code is designed to be modular and expandable, with the intention that users may wish to experiment with their own methods or algorithms. Finally, the code should be flexible – one should be able to generate models for systems ranging in complexity from a simple single DOF mass and spring, to a three-dimensional multibody vehicle model.

The software is developed using the MATLAB computing platform, for a number of reasons. It is widely popular in both industry and academia, it is available for multiple operating systems, and it provides a number of powerful and useful utilities. In addition, a free, open-source mathematical programming language, Octave, uses almost identical syntax, making the EoM code essentially free to anyone motivated enough to experiment with it.

The code works by automatically formulating the equations of motion of the various components in the vehicle, starting from a list of their properties. In more mathematically precise terms, the equations of motion are differential equations: one can't simply solve them for an answer, but rather, they predict how motion changes over time.

There are many well-known commercial vehicle simulation codes on the market that are capable of forming and solving these equations, and they may be used to predict, for example, drag strip, lap time, or ride quality performance. These commercial codes typically include models for non-linear phenomena, such as aerodynamics, tires operating near the limit of traction forces, or suspension dampers with separate high-speed and low-speed characteristics. Given some initial state, they can generate a time history of the motion, usually as numerical values rather than as a formula or function. More recently, codes with algebraic solvers have appeared on the market; these can actually give a closed form solution for some systems, but they are not currently in wide use.

The Windsor EoM code is different, in that it is designed from the outset to use linear approximations of these complex non-linear behaviors. As a consequence, it is less accurate for describing certain types of behavior, and therefore not the ideal tool for predicting specific results, such as a lap times, etc. However, the linearization of the equations of motion enables their solution to be carried out in an



ABOVE: **AN EXAMPLE OUTPUT FROM THE RIGID-RIDER BICYCLE MODEL, AN EIGENVALUE SWEEP**

entirely different fashion. Unlike non-linear differential equations, which must almost always be solved numerically as functions of time, the general solution of linear differential equations is already known. The solution will always be some combination of sinusoidal oscillatory motion, and exponential growth or decay. The linear model provides a more qualitative solution, independent of the initial state of the system. The specifics of the mechanical system or vehicle in question determine the frequencies of these oscillations and the rates of the exponential behaviors. In effect, using a linear model enables a more general characterization of the vehicle behavior.

Traditional models

In the vehicle dynamics literature, there are a number of models that have been widely used for many years, and are very well understood. One example is the 'quarter-car' suspension model, where the vehicle is represented as two masses, one sprung and one unsprung, and the tire and suspension are modeled as simple linear springs. Although decidedly simplified, the quarter-car model enables prediction of wheel hop frequencies and ride quality.

Another example is the yaw-plane or 'bicycle' handling model, where the vehicle is treated as a single rigid body, and the tire forces are treated as linear functions of tire slip angle. The yaw-plane model can be used to give precise mathematical definitions to the terms oversteer and understeer, and can give information about vehicle stability.

The EoM software enables one to develop these traditional vehicle models quickly and easily. In fact, the students in the University of Windsor's automotive engineering program use it for precisely this purpose in their undergraduate vehicle dynamics course. In addition, the EoM code is capable of generating the equations of motion of more complex three-dimensional multibody systems. Models of a truck and trailer combination, a 'rigid-rider' bicycle, and a four-wheel-drive off-road vehicle have all been built and verified against published results in the literature.

The vehicle models are built up by specifying the properties of the individual bodies that make up the system (such as the mass) and the moments of inertia, and the various means by which these bodies are connected. The connections can be specified as either flexible, such as a suspension spring or bushing, or as rigid, such as a ball joint or hinge. This distinction is quite important when formulating the equations of motion. The flexible connections are used to develop the stiffness matrix, and the rigid connections are used to form the constraint equations. These constraint equations ultimately determine the number of coordinates that are required by the model. The code has a library of various connections that can be modeled.

One of the interesting features of the EoM code is its ability to model 'non-holonomic' systems, that is, systems where the constraints on the motion cannot be expressed in terms of the locations or orientations of the bodies, but instead must be written in terms of their velocities.

A typical example of this type of constraint would be the 'no-slip' tire used in many simple vehicle models; the tire is treated as having a single point of contact with the road, and the velocity of that point of contact must always remain parallel to the tire. This is in contrast to, for example, a ball joint, which essentially requires the location of a point fixed in each of the two connected bodies to be at a common location.

Traditionally, non-holonomic systems have proved to be more challenging to accommodate in the development of computer-aided modeling tools. Coincidentally, many of the well-known vehicle models involve some sort of non-holonomic constraint.

Future developments

Unfortunately, no graphical user interface exists for EoM at present, but the research group is exploring a web-based system that would enable users to generate and analyze their models with only an internet connection and a browser. Currently, the output is processed using the document preparation software LaTeX to produce charts and graphs. Although not widely used, LaTeX is also open-source, and is popular in academia, especially in engineering and mathematics, for its capabilities in typesetting documents that include equations.

Development of the EoM code itself is also ongoing. The group is particularly interested in expanding the joint library, and in developing more benchmark models to validate the solutions from EoM. It can be downloaded freely from the University of Windsor Vehicle Dynamics and Control Research Group's website at www.uwindsor.ca/vdc.

ABOUT WINDSOR

Situated in Windsor, Ontario, the University of Windsor benefits from its proximity to Detroit. The university offers degrees in a number of engineering disciplines, and is well known for its focus on automotive engineering. The Engineering Faculty is currently preparing for a move to its new home in the Centre for Engineering Innovation, scheduled to open in autumn 2012. With 300,000ft² of space dedicated to the Engineering Faculty, it is the largest capital investment in the history of the university. The new center will transform and greatly enhance the student experience, and is a major step forward for the university.

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Back to school

DAMIAN HARTY HAS JOINED COVENTRY UNIVERSITY AS A SENIOR RESEARCH FELLOW IN SYSTEM & VEHICLE DYNAMICS. HERE, HE DISCUSSES ISSUES CLOSE TO HIS HEART, SUCH AS: RESISTING THE URGE TO OVER-COMPLICATE...

"Einstein once said, 'As simple as possible, but not simpler.' That feels like pretty good advice to me"

Coventry University has a distinctive, hands-on teaching style and I aim to contribute to that. As well as teaching, I have a clear remit to research new and emerging ideas – this is a great time to be an engineer in the automotive industry.

One of the ideas being studied is the so-called 'intelligent engineering process'. Like many 'new' ideas, this is just the formalization of things that great practitioners were already doing. The process is really all about working out what the question is; my experience is that when that is known, the answer lays itself out quite readily.

First and foremost is the idea that we must know what success looks like. We use terms such as 'product objectives' to describe what we want the thing to do. Note that this is quite different to what we want it to be. Not knowing what we want the product to do leads to a whole load of pet theories and conflicting objectives, which consume resources at a phenomenal rate.

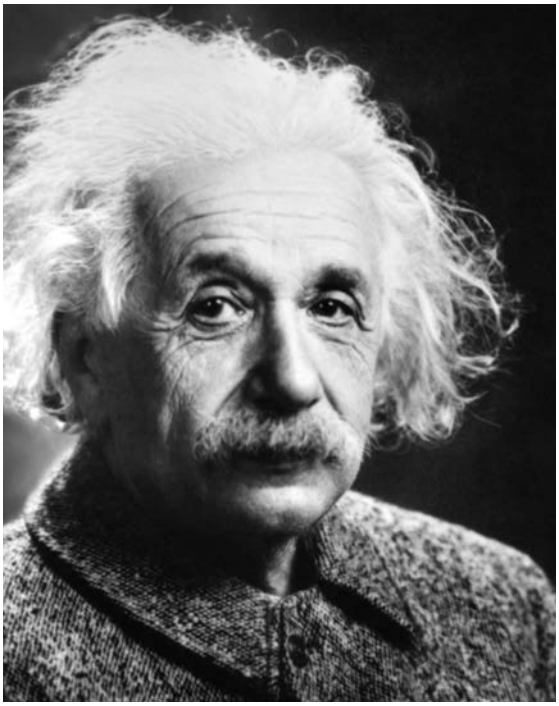
The intelligent engineering process is about using any and every means available to map the relationship between what the product is – its 'critical characteristics' – and its performance. If that were all that was needed, life would be quite simple; with finite resources, intelligence is needed to ensure we prioritize those things that move the needle.

It is also important to understand which aspects of the design are fixed first and which remain volatile, so as to avoid iterating over items that were already defined, which again wastes time and resources; remember, we are short of those.

In a motorsport project, performance is quite readily defined as lap time or stage time. Such measures are not so readily available for road cars – but this doesn't mean they don't exist. I can understand issues in defining sound quality (is it Mozart or Motörhead?) but in vehicle dynamics I am convinced that performance is entirely measurable in principle. The vehicle, operated by a human, has a small number of inputs and a small number of output states. This isn't to say there aren't aspects of difficulty in practice, of course.

Works such as S.S. Stevens' *Psychophysics* have long since defined the relationship between physical quantities and perceived quantities; the science of humans as closed-loop control systems has been long understood in airplane design – delays are the enemy of control.

An illuminating observation I've made is the existence of 'hygiene factors'. This is a term borrowed from management theory to describe some aspect that, if poorly controlled, can lead to a loss of motivation. Once a threshold is reached, however, it does not further influence matters. The example I use for motorsport is the crew intercom performance in a rally car. If the intercom volume is low and a rally driver cannot hear the co-driver's reading of pace notes, the driver will slow down and drive visually. If from here the intercom volume is increased, the driver will be able to go faster; however, to conclude that yet more volume would increase pace further would clearly be nonsensical.



And so it is with many aspects of vehicle dynamics. If the primary ride vibration is below the perception threshold, can making it 'more imperceptible' be justified? If on-center response is so fast it appears instantaneous, can spending time and effort to make it faster be justified? If the parking efforts are light enough, can more effort be justified in making them lighter, particularly if it compromises other aspects of steering feel?

The key idea with hygiene factors is to get them right and then leave them alone. It takes a lot of confidence to do that, and many organizations don't have the confidence in their processes to do it; this is a failing in our collective confidence in engineering methods. We need to get better at it, particularly in vehicle dynamics.

Three key lessons emerge for my students. The first is that: life is not an exam question.

Time and again I am struck by students who are rather offended by the idea that life is not an exam question, with just the right equations, every piece of

> **"If the primary ride vibration is below the perception threshold, can making it 'more imperceptible' be justified?"**
> Damian Harty

required information provided, no spurious, redundant, or contradictory data, and just the right amount of time available to do it.

Exam questions have their place – and it's in exams, of course. But the ability to answer exam questions is not what's needed in the real world.

The second lesson is: accuracy is not usefulness. Answers to questions are more useful the sooner they are known. When a vehicle is on sale or in the hands of the test team, it's a bit late to be finding an issue.

Sir Isaac Newton described in 1687 how stuff moves, but we had to wait for the Apollo program to turn digital computing into practical reality. For quite some time we have been able to do a whole load of clever things predictively.

What is recent, and changing all the time, is how quickly we can do it, and this speed really counts – the same answer known sooner is more valuable.

More accuracy than is needed is positively wasteful of resources and time, and should be rigorously discouraged.

As we move to novel configurations and packages with the rush of electric and hybrid architectures, the ability to usefully discern the consequences of decisions is important.

And the third lesson: you need to do it as well as calculate it.

Some aspects of vehicle dynamics defy succinct quantification. Personally, I'm fairly convinced that most things succumb if you look closely enough. Nevertheless, items such as steering feel and road texture feel are remarkably difficult to get to grips with, but annoyingly obvious to journalists and customers if they are wrong.

How difficult is it to use data measured by someone else or the outputs from a model if you have no idea about the emotional reaction they engender? What rate-of-change of body slip angle feels threatening? If you've never held the wheel of a car in a limit situation – or been unable to mentally track the vehicle at the time – would you even know it was an important measure?

A new MSc course in Vehicle Performance and Dynamics uses the intelligent engineering process as the thread connecting many aspects of detail and theory. Einstein once said, "As simple as possible, but not simpler." That feels like pretty good advice to me.

The must-attend event of the year!

THE ANNUAL SHOWCASE FOR THE LATEST CHASSIS TECHNOLOGIES AND VEHICLE DYNAMICS DEVELOPMENT TOOLS RETURNS TO MESSE STUTTGART ON JUNE 12-14. TOP OF THE BILL IS A **FIRST-RATE CONFERENCE** THAT IS FREE TO ATTEND!

★★★★★ Featuring one of the best conferences of the year – and it's **FREE** to attend!

VDI is delighted to announce a first-rate line-up of speakers for the Open Technology Forum at Vehicle Dynamics Expo 2012, the must-attend exhibition for all vehicle dynamicists.

Five OEMs from across Europe and Asia will take their place alongside the numerous providers of chassis components, dynamics development tools, and specialist consultancies during the course of the three-day program. In all, more than 25 speakers are due to present, and with each slot extended to 30 minutes this year there will be plenty of time for each of them to get into lots of fascinating depth!

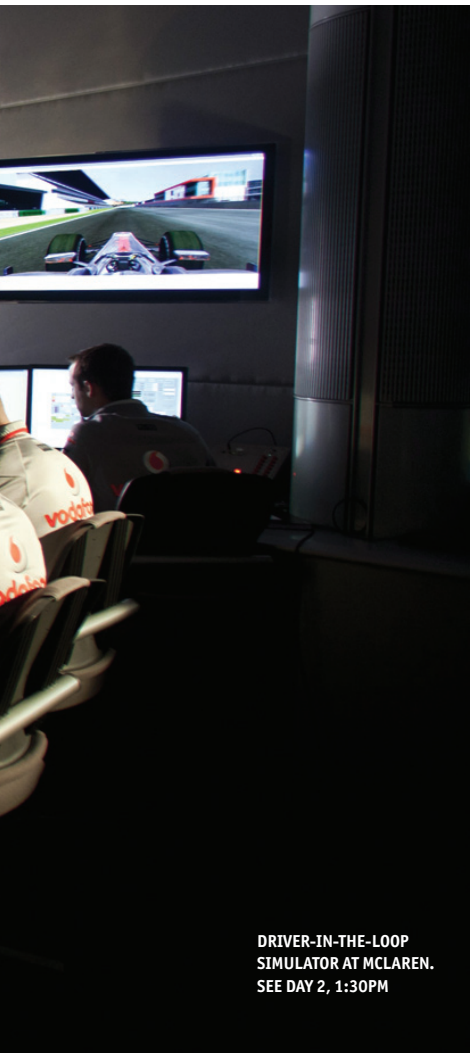
In the following pages you'll find the draft program in full. We've also picked out some of the highlights of the conference. Be sure to head to www.vehicledynamics-expo.com for updates as the event approaches.

The exhibition

Alongside the Open Technology Forum, visitors to the Messe Stuttgart can discover some of the very latest technologies and services in the exhibition area. Flick to page 51 for news from some of the show's exhibitors, all of them focused on chassis and dynamics development.

New for 2012 is the show's relocation to Hall 1, so it'll be happening right alongside Automotive Testing Expo Europe, which with over 70 relevant, dynamics companies, including proving grounds, simulation companies, and test rig manufacturers, will only further enhance the value of attending.

Vehicle Dynamics Expo 2012 gets underway on June 12 at 10:00am, and the Open Technology Forum kicks off at 11:00am. Sign up for your free visitor pass at www.vehicledynamics-expo.com.



DRIVER-IN-THE-LOOP SIMULATOR AT MCLAREN. SEE DAY 2, 1:30PM

Open Technology Forum

FREE TO ATTEND!

Day 1
Tuesday, June 12
Suspension, damping, steering: tuning, development, and testing

11:00am
Drive innovation and integration into your test research with Moog
Erik Kuiper, senior application engineer, Moog, Netherlands
Moog's motion control technologies expertise leverages innovation in automotive test research. Its test solutions are based on the concept of the flexibility to 'Test it your way'. Based on the Moog technology platform and Test software architecture, users can select the exact level of performance needed to match desired test requirements. Examples that will be discussed are vehicle dynamics testing with Moog's latest driving simulator technology, and vehicle component testing with Moog's Electric or Hydraulic Simulation Tables, including the Integrated Test Suite software, which accommodates the simplest and most complex tests due to its unique architecture.

11:30am
Engineer driver training: a vital cog in the wheel
Simon Poole, director, Pro2, UK
Do dynamics engineers need to be good drivers, and how can this help them develop better vehicles? How important is it to establish a particular dynamic DNA in a marque and how is this translated for new engineers? Establishing a standard for development driving can deliver rewards very quickly and enhance the vehicle development process. As well as the obvious health and safety benefits of trained drivers, developing subjective feel for vehicle attributes can be taught; for inexperienced engineers it's the easiest and quickest way for them to begin to help in developing better vehicles.

12:00pm
MR semi-active suspensions: modeling, fault detection, and control
Jorge de Jesús Lozoya-Santos, researcher, Tecnológico de Monterrey, Mexico
The magnetorheological damper is the

"Establishing a standard for development driving can deliver rewards very quickly and enhance the development process"
Simon Poole, director, Pro2

more efficient device in semi-active suspensions. New experimental designs orientated to specific driving conditions are proposed and validated in continuous, discrete, and constant manipulation. Observed characteristics enable the design and identification of a non-linear model with computing advantages. The model has enabled the development of a condition monitoring method (MMMR) for MR dampers and a model-free controller, both being validated in CarSim with a non-linear semi-active suspension in MATLAB. These new approaches lead to optimum detection of faulty MR damper and the improvement of the compromise between comfort and roadholding.

SUBARU BRZ

You'll have seen by now that our jury of independent experts voted the Subaru BRZ and its doppelgänger, the Toyota GT86, as our Car of the Year for 2012. So what better highlight for Day 1's Suspension, Damping and Steering session than a presentation entitled 'Dynamics of the Subaru BRZ' (1:00pm), to be given by two of the car's engineering team at Fuji Heavy Industries: Hiroshi Watahiki, deputy general manager of the total vehicle performance integration department, and Kazuo Ikeda, manager of the chassis design department. Be sure to get there early for this one – it'll be standing room only.

12:30pm
Vehicle subsystems control using the concept of moding
Prashant J. Narula, software development engineer, Adam Opel AG, Germany
A control architecture based on the concept of moding is presented, wherein a central controller selects a specific subsystem operating mode rather than generating direct physical control signals. By selecting the best operating mode of each subsystem, the moding algorithm evaluates the driver's direct input (pre-selection of a sports or touring button) and analyzes available sensor signals to detect the current driving situation and driving style. The driving situation and style are recognized by classifying the vehicle dynamics data. A moding table is then consulted to alter vehicle systems that support the driver's intent, the ride feeling, and chassis safety in real time.

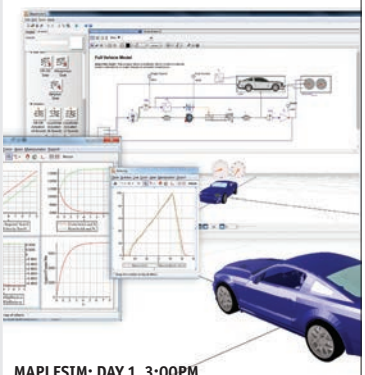
1:00pm
Dynamics of the Subaru BRZ
Hiroshi Watahiki, deputy general manager, total vehicle performance integration department, Fuji Heavy Industries Ltd, Japan
Kazuo Ikeda, manager, chassis design department, Subaru Engineering Division, Japan
This presentation will introduce Subaru's unique expertise for achieving BRZ's distinctive performance, which is dubbed "pure handling delight".

1:30pm
MUST-SEE PAPER!
Using driver simulators to accelerate car development
Mike Phillips, head of motorsport, McLaren Applied Technologies, UK
McLaren has been at the forefront of using simulation tools and driver-in-the-loop simulators in Formula 1 for many years. More recently, McLaren has used similar technology to develop the dynamic performance of its current and future road cars. The ability to simulate a range of options before the actual prototypes are available to test has created some major advantages. This presentation seeks to highlight the potential in using high dynamic range driver-in-the-loop simulation to develop road cars, and the potential time and cost savings that could be achieved.

2:00pm
Running Simulink models natively in co-simulation with Cruden software
Maarten van Donselaar, CEO, Cruden BV, Netherlands
Cruden explains the benefits of ePhyse Net, a revolutionary new package that enables Simulink models to run natively in co-simulation with Racer Pro. This means Cruden simulators can seamlessly integrate not only with the Cruden Simulink Vehicle Model (CSVM) or customer in-house-developed models, but also with VI-Grade, IPG CarMaker, veDYNA, CarSim, SIMPACK, or other vehicle modeling packages. With ePhyse Net, third-party libraries (e.g. Bosch ESP) can be used as there is no need to compile the code, which means there is no need for Real Time Workshop, saving time (no modification required) and money.

2:30pm
Role of hybrid simulation in vehicle development
Diego Minen, technical director, VI-Grade, Germany
Offline vehicle handling/ride simulation is a common tool in automotive engineering, but accuracy of results can be proved only when real prototypes are built: test drivers and track engineers can influence the vehicle design only too late. With the introduction of VI-DriveSim it is now possible to implement a new validation/improvement stage in the design cycle by letting the digital car be driven by real testers. In doing so, the team of developers can get drivers' comments on their feeling during simulated interactive maneuvers, can identify model issues, and iterate on all the accessible parameters available, modifying SW and HW input setups.

3:00pm
High-fidelity transmission simulation for vehicle dynamics studies
Dr Orang Vahid, senior modeling engineer, Maplesoft Europe GmbH, Germany
This presentation will introduce a new driveline modeling library for MapleSim that enables the powertrain engineer to develop detailed transmission models and implement them in the full vehicle model to study the effect of gear-selection strategies – including shift timings and torque losses – on the overall performance, fuel efficiency, and ride quality. This approach leverages the advanced symbolic technologies from Maplesoft for developing highly efficient code for real-time implementation, and the presentation will cover results from a recent hardware-in-the-loop project that integrates the detailed powertrain model into a full-vehicle model from VI-Grade.



MAPLESIM: DAY 1, 3:00PM

3:30pm
Virtual optimization of suspension kinematics and compliance with dSPACE ASM
Tino Schulze, product manager, dSPACE GmbH, Germany
Vehicle dynamics handling models are an industry standard, especially for ECU testing. Using such models for testing kinematics and compliance configurations is a relatively new field of application. With a new tool chain,

dSPACE's Automotive Simulation Models (ASM) presents an automated calculation of kinematics look-up tables from geometric parameters. On top of this pre-processing step, compliance parameters are calculated using optimization algorithms to meet target vehicle dynamics performance criteria such as lateral acceleration. This enables vehicle dynamics engineers to estimate proper bushing parameters virtually before the final real-vehicle testing.

Day 2
Wednesday, June 13
Suspension, damping, steering: tuning, development, and testing

10:30am
MUST-SEE PAPER!
Full vehicle simulation of complete durability schedule
Dr Marco Franco Spinelli, Virtual Analysis Manager, Fiat SpA, Italy
Simulation activities can be used to predict loads acting on chassis and body before going on the track with a real vehicle. The current status of models shows very good prediction of loads compared with the measurements and offers the opportunity to simulate very complex durability schedules or compare tracks and worldwide programs. The combination of durability and vehicle dynamics simulation saves time and eliminates the costs of modification of components in the event of structural failures. This presentation will recount recent experiences at Fiat and Chrysler Group.

11:00am
DVS: new technology for substituting real sensors with virtual sensors
Prof. Mario Milanese, managing director, Modelway Srl, Italy
Virtual sensors are software devices able to estimate a variable of interest using other correlated variables. It has two purposes: 1. Recovery of real sensor faults: the estimates of the virtual sensor can be used if a fault or a malfunctioning of the real sensor is detected; 2. Cost reduction: the real sensor can be replaced by the virtual one. In this presentation, a new virtual sensor technology is unveiled where the sensor (Direct Virtual Sensor) is directly designed from the experimental data. The DVS technology outperforms Kalman filtering technology. Some applications related to the automotive field will be illustrated.

11:30am
Active human body models for vehicle dynamics simulation
Dr Valentin Keppler, CEO, Biomotion Solutions GbR, Germany
Vehicle dynamics simulation can be improved by modeling drivers as active humans instead of regarding them as passive lumped masses. This is demonstrated by analyzing ride dynamics of a coupled motorcycle rider system. Commonly, in motorcycle simulation the rider is modeled as a passive lumped mass system, and rider control is modeled as an artificial steering torque between the frame and the fork. Using an active biomechanical rider that is capable of steering the motorcycle by moving the handlebars through hand-arm movements, the differences in simulation results compared with a passive rider model have been analyzed.

Designing in Safety

12:00pm
Development of procedures and criteria for active safety assessment
Marco Pesce, vehicle dynamics senior specialist, Centro Ricerche Fiat, Italy
The importance of standard procedures and criteria for active safety assessment is well known to experts in the sector, mainly as a tool for system development by track tests and simulation: each OEM relies on its own procedures to get higher performance and safety goals, besides international standards and legal regulation. But understanding the true effectiveness of active systems in real-world conditions and providing this information to the final road user is important as well: it is a newer, difficult challenge, specifically addressed in recent years by some EU-funded projects and NCAP organizations, OEMs, and third parties.

12:30pm
Stress distribution in the tire: road contact patch
Prof. Gabriel Anghelache, professor, University Politehnica of Bucharest, Romania
Vehicle dynamics is widely determined by the tire-road interaction. Loads exerted in the contact patch are distributed as normal, and shear stresses play a major role in vehicle support and generation of rolling resistance, traction/braking, and lateral forces. These stresses also influence aquaplaning behavior, rolling noise, and vibration. The presentation shows the results of experimental research on tire-road contact stress distribution, measured in the laboratory and in real rolling conditions, for truck and passenger car tires. Aspects regarding the measurement setup are also presented. Comparison and conclusions on the results are included.

Virtual sensors

Now here's something really new: substituting real sensors for virtual sensors. Prof. Mario Milanese from Modelway in Italy has a slot at 11:00am on Day 2 to explain how a Direct Virtual Sensor (DVS) can be directly designed from experimental data. Such devices have two purposes, he argues: recovery of real sensor faults (the DVS's estimates can be used if a fault or a malfunction of a real sensor is detected); and everybody's favorite benefit, cost reduction – replacing a real sensor with the virtual one. Prof. Milanese believes that DVS technology outperforms Kalman filtering technology, and plans to use the Forum to illustrate some applications related to the automotive field.

1:00pm
Tire pressure and TPMS in end customer practice
Jörg Sturmhoebel, CMO, NIRA Dynamics AB, Sweden
How do drivers handle tire pressure? Do they know what role tire pressure plays and how TPMS works? What do they expect from TPMS? NIRA has conducted a survey.

1:30pm
Commercial vehicle dynamics
Martin Reder, director of engineering, BWI Group, USA
This paper presents the process used for establishing the suspension configuration and the stability control system for a multi-use commercial vehicle with a high center of gravity. The stability control system and suspension were designed to ensure vehicle stability when heavily loaded, while also providing pleasing ride and handling qualities when lightly loaded. BWI Group is the supplier of the stability control system, and provided chassis integration services and testing of the stability control system under contract to the vehicle design house. This presentation describes the process used to ensure that all vehicle dynamics targets were met.

2:00pm
Determination of tire parameters based on tire forces, tire drift, and toe angle
Michael Dörr, R&D manager, Kistler Automotive GmbH, Germany
Tire development helps to improve the ride and handling and safety of a vehicle. Some of the important values are the lateral and transversal force that a tire can consign to the surface. These forces are influenced by the tire drift and the toe angle. Kistler provides a measuring system to measure all the influencing parameters. The results enable the user to improve the tire development, optimization of suspension, and also to correlate the results to measurements done on a test rig.

MFCS POGOSTIK: DAY 3, 12:30PM

Design and component innovation

2:30pm
MUST-SEE PAPER!
G-Vectoring: new vehicle dynamics control technology for safe driving
Dr Makoto Yamakado, senior researcher, Hitachi Ltd, Japan
Hitachi has developed a world-first technology for vehicle dynamics control that achieves smooth and stable cornering by automatically controlling longitudinal acceleration and deceleration based on how the driver controls speed as the vehicle travels around a corner. A strong correlation between longitudinal acceleration and lateral jerk can be found in the smooth driving of expert drivers and is called G-Vectoring Control. G-Vectoring Control achieves safe and comfortable driving and is good for the environment because it minimizes energy loss and tire wear. Hitachi is extending the use of this technology in various systems.

Lightweight chassis

The need to reduce weight hasn't been this fashionable since Colin Chapman was adding lightness to Lotuses back in the 1950s and 60s. On Day 3 at 11:30am, Darshan Wale, manager for suspension systems at Tata Motors, India, will be presenting on the subject of 'Passenger car chassis strategy to make vehicles lighter'. He will examine how the weight of everyday components such as MacPherson struts and twist-beam axles can be reduced. "Using lightweight materials and opting for new technology should be the roadmap," he says.

DAMPTRONIC SELECT: DAY 3, 3:00PM

3:00pm
DampTronic select: a cost-efficient two-stage damping system
Klaus Schmidt, head of development Active Systems, ThyssenKrupp Bilstein, Germany
With the DampTronic select adjustable damper ThyssenKrupp has developed a robust, cost-effective system that gives drivers the option to switch to a tighter, more agile shock absorber setting – a sports suspension at the touch of a button. Compared with a continuously variable system, the new development features a simplified switching valve and dispenses with sensors and a complex control unit.

3:30pm
Control knobs: integrated plastic bearing solutions and advantages
Mark Watkins, EMEA sales manager, BNL (UK) Limited, UK
The flexibility of design afforded by plastics can be applied to functional aspects by considering the use of integrated plastic bearing solutions for features such as control knobs. Integrating components and functions in a molded plastic bearing solution maximizes the use of space, reduces weight and wobble, allows for design innovation such as hollow centers for display features, achieves both rotary and axial-push movement in one, and meets haptic requirements for smooth movement and consistent low torque levels.

Day 3
Thursday, June 14
Design and component innovation

10:30am
Tenneco's electronic damping and advanced suspension portfolio
Sjaak Schel, R&D technical team leader, Tenneco, Belgium
The presentation will describe the features of Tenneco's different electronic damping systems and advanced suspension systems.

11:00am
Suspension topology for maximized control of traction power
Dr Armin Zuber, responsible for advanced chassis, Benteler Automobiltechnik GmbH, Germany
Magnus Roland, president & CEO, S2AB, Sweden
Mind and consciousness are major operators in vehicle dynamics. The suspension topology orchestrates the transmitted multidimensional power pulse propagation to the human sensory system. Power operates reciprocally in short instantaneous moments of the present. Tire traction power dynamics compares to engine indicated power characteristics to be controlled within milliseconds. As consciousness is inaccessible to direct measures, the orchestrated power pulse propagation characteristics is made compatible with human capability from detecting phenomena of hidden characteristics from parameters inaccessible to direct measures. A S2AB/Benteler/Koenigsegg project will demonstrate the validity of used physical principles of structural bonding on atomic levels beyond Newtonian mechanics.

11:30am
Passenger car chassis strategy to make vehicles lighter
Darshan Wale, manager, suspension systems, Tata Motors, India
Making lightweight and durable chassis should be the chassis strategy in future. This presentation will examine some of the components to be considered to make chassis lighter: MacPherson struts, steering systems, springs, twist-beam, etc. Lightweight materials and new technology should be the roadmap.

12:00pm
iTORQ: benefits of individual wheel control on vehicle dynamics performance
Jonathan Webb, product manager, chassis development, IDIADA AT, Spain
An electric powertrain with individual control over the tractive forces in each wheel opens up a world of possibilities in vehicle performance and driving dynamics. To explore and develop these possibilities, IDIADA has developed a prototype vehicle with four independent electric motors. This architecture opens up new avenues in the development of torque vectoring strategies and regenerative braking controllers. With iTORQ, engineers evaluate driver perception of various controller algorithms as modifiers to driver input and vehicle response. iTORQ also provides a powerful tool for the assessment of potential system failure and its impact on vehicle stability and control.

12:30pm
New perspectives for axial bushings in stabilizer linkages
Christoph Esswein, senior application engineer, Maclean-Fogg Component Solutions GmbH, Germany
Stabilizer linkages have a large influence on the effectiveness of the stabilizer bar as well as on the precision of the whole chassis system. Ball joints and radial bushings are the most common interfaces for this application. The axial bushing is seldom used because of its known deficits regarding axial stiffness and angular flexibility. Dipl.-Wirtsch.-Ing. Christoph Esswein from MFCS presents the PogoStik as a double axial bushing linkage design to address these issues, and discusses the new perspectives this link offers to the chassis engineer.

1:00pm
Lightweight semi-active suspension for electric vehicles
Dr Joachim Funke, general manager, BU industry, Fludicon GmbH, Germany
Fludicon's semi-active suspension system, eRRide, is the ideal solution for electric vehicles. Using an application example of an electric vehicle with wheel hub motors, this presentation will show how semi-active suspension can bring comfort and safety to difficult suspension situations and help electric vehicles save energy. Suspensions of electric vehicles often present the dynamicist with extremely high wheel masses and short strokes. The suspension has to be lightweight. High initial vehicle prices raise customers' expectations of comfort and safety. These multiple design conflicts can be solved by semi-active, ER-based suspension technologies.

Please note, this program is subject to change. Updates are at www.vehicledynamics-expo.com

Exhibition highlights

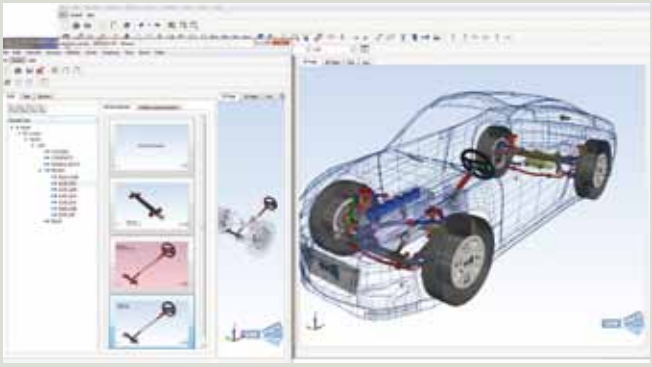
VEHICLE DYNAMICS EXPO 2012, JUNE 12-14, 2012, NEW MESSE STUTTGART, GERMANY

Bourns expands Mexican plant

Bourns has announced an expansion of its production facility in Chihuahua, Mexico. The 22,000ft² manufacturing floor space extension will be used for the production of Bourns' automotive position, speed, and torque sensors. "The expansion of this plant strengthens Bourns' leadership role in sensor manufacturing by providing an increased product offering and enhanced customer service," said Sergio Valencia, plant manager at Bourns' Chihuahua plant. "Building on 65 years of growth, Bourns is continuing to expand through acquisitions, opening new facilities, and enlarging current plants."
Booth V1481

Support for HI-REACH project

Expo exhibitor Hans Meier GmbH has said that it will be supporting the HI-REACH project initiative, the objective of which is to raise the overall quality in the supply of components to motorcycle applications, through eco-efficiency. The company will the play the role of identifying market needs and new business opportunities. Suppliers of different components share a common product process development model, where the common denominator is represented by the excellence in performance and the extensive application of eco-efficiency and improvement of lifecycle environmental footprint.
Booth V1279



SIMPACK Wizard

SIMPACK will present the SIMPACK Wizard, which allows its technology to be deployed throughout companies for use by non-SIMPACK experts. The Wizard enables easy setup and use of standardized models and analysis scenarios.

It also enables SIMPACK experts to create easy-to-use modeling environments for non-MBS experts. Once the Wizard database is ready, component models of varying complexity can be chosen by Wizard users and fed with parameter data. Likewise, analysis scenarios and report analysis can be selected. SIMPACK will then automatically assemble the full system models, run the selected simulation scenarios, and generate the analysis reports. The number of component variants, analysis scenarios, and outlay of reports can all be specified and created in-house by the expert user.

This step forward makes complex MBS analyses easily available to part-time users. Standard analyses are no longer restricted to low-fidelity, non-company specific models.
Booth V1478

Lightweight braking systems

Supporting both low niche and high-volume OE customers, AP Racing develops brake and clutch systems for high-performance, hybrid, and electric car manufacturers. The company has extensive experience of alternative tooling and manufacturing techniques to create solutions for customer project specifics and volumes. Visit the stand to discover AP Racing's lightweight braking systems, which offer improved range and fuel efficiency for hybrid and electric cars, with its innovative brake caliper designs providing reduced drag combined with high stiffness opposed piston caliper solutions.
Booth V1386

Air suspension compressors

Wabco will unveil its latest air suspension compressor developments. Wabco's engineering team has successfully reduced the compressor's weight by 20%, while increasing its functionality. Another advancement is Wabco's new integrated air dryer, which operates with a simplified pneumatic scheme and integrates the former external air filter into a common housing, making it easier for the OEM to install the overall system content. Also on display will be ECUs for air suspension and damper control, plus vacuum pumps for passenger car braking systems.
Booth V1285

Who to meet:

Maarten van Donselaar, Cruden

Maarten van Donselaar is Cruden's CEO of eight years. He has a background in vehicle dynamics and has had a long career in the automotive industry, working previously for The Mathworks and TNO Automotive, before starting up his own virtual engineering company in 1999.

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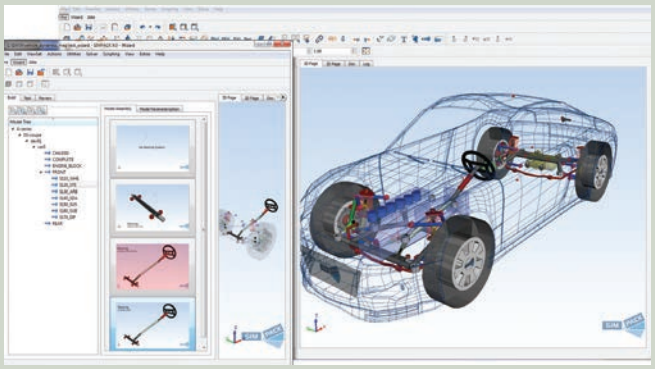

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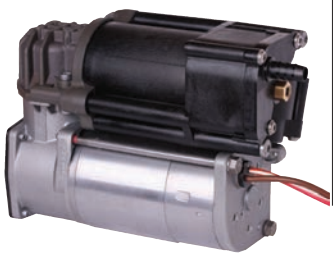
Booth V1386

Compressor developments

WABCO will present its latest portfolio of vacuum pumps for passenger car braking systems for diesel and GDI engines. The company will also unveil its latest compressor developments with multiple benefits. For example, WABCO's engineering team has successfully reduced the compressor's weight by 20%, while increasing its functionality. Another advancement is WABCO's new integrated air dryer, which operates with a simplified pneumatic scheme and integrates the former external air filter into a common housing, making it easier for the OEM to install the overall system content.
Booth V1285



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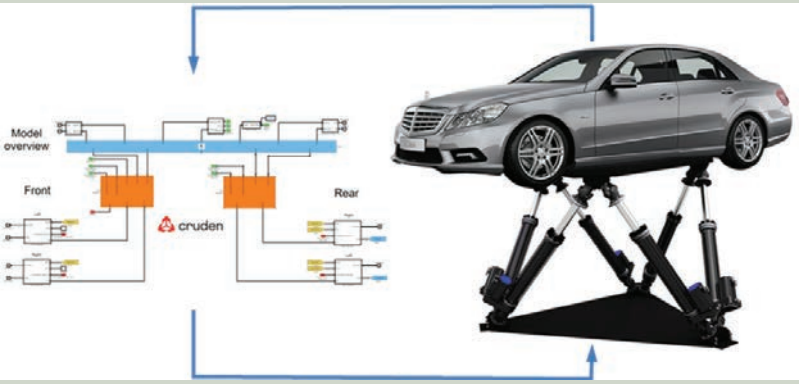
FREE TO ATTEND!

Co-simulation software package

Cruden will be showing the latest add-on to its Racer Pro software. ePhyse Net is a new package that enables Simulink models to run natively in co-simulation with Racer Pro. Customers have the choice of seamless integration with Cruden's own Simulink Vehicle Model, their own in-house-developed models, or with vehicle modeling packages such as VI-Grade, IPG CarMaker, veDYNA, CarSim, and SIMPACK.

"A big advantage of ePhyse Net is that third-party libraries such as Bosch ESP can be used since there is no need to compile the code. This means there is no need for Real-Time Workshop. ePhyse Net saves engineering teams money and development time, because it lets them use their own, unmodified vehicle models," said Maarten van Donselaar, CEO of Cruden. Visitors to the stand can check out ePhyse Net's extremely detailed customer vehicle mode. It is built up in MATLAB/Simulink and runs Pacejka 6.1-based tire models, and supports dynamic rolling radius. Because of the model's open architecture, users can easily modify or replace building blocks, or choose to use external vehicle models in the simulator.

Booth V1484



Air suspension expert

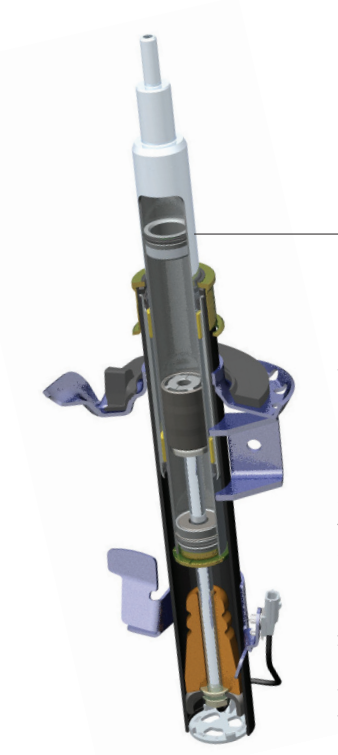
With more than 30 years' experience with air spring technology, Vehicle Dynamics Expo returnee Continental has its air suspension systems on luxury- and other top-of-the-range cars, SUVs, minivans, pick-ups, and vans. Continental has developed air suspension systems with a switchable auxiliary reservoir, making it possible to have a very comfortable setup or a very sporty one, at the touch of a button. Its electronic suspension systems are individually adapted according to vehicle type. Customer benefits can be realized very easily through auxiliary functions such as an adaptive loading sill, or easy-entry and trailer modes. By integrating a new generation of air spring bellows into the air spring- and damper modules, compact- and medium-sized vehicles can now be so equipped, too.

Booth V1282

MapleSim's add-on software

Maplesoft's MapleSim Driveline Component Library is an add-on tool for MapleSim – the physical modeling and simulation tool. The new software is a collection of components for driveline modeling applications. The MapleSim add-on covers all stages in the powertrain, from the engine to the differential, wheels, and road loads, as well as vehicle dynamics. Visitors can see how library components use a causal approach to model development, where the user can connect the components together in the required configuration without worrying about torque direction and load flow.

Booth V1472



Third generation of MagneRide

Global braking and chassis systems specialist BWI Group will exhibit the third generation of its MagneRide controlled suspension system at Vehicle Dynamics Expo. The company will also demonstrate its chassis expertise with its latest passive dampers, active stabilizer bar systems, magnetorheological powertrain mounts, and ABS systems.

The third generation of BWI Group's MagneRide was first introduced on the Range Rover Evoque with its Adaptive Dynamics technology. The addition of a twin-wire dual coil actuator to the system, and a bespoke ECU with optimized control algorithms, provides a faster response and a greater range of damping control, to deliver very high levels of traction, stability, and comfort, both on and off the road.

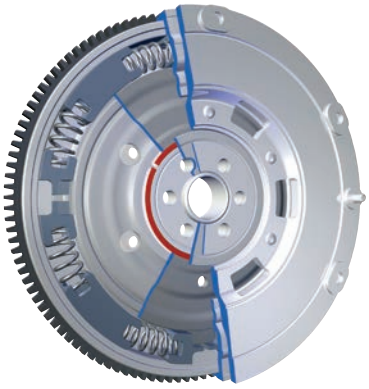
"MagneRide technology has been well-proven on high-performance cars, supercars, and large SUVs," said BWI's Olivier Raynauld. "The third generation of MagneRide, with faster response and wider dynamic range, effectively removes the need for chassis engineers to compromise between comfort and handling."

Booth V1162

Customized automotive solutions

Norglide composite bearings and Rencol tolerance rings are being showcased by Saint-Gobain. With its self-lubricating layer of polytetrafluoroethylene, custom-developed for each customer application, the Norglide range has been developed to enhance friction control in automotive mechanisms, boosting vehicle performance. Rencol tolerance rings have been designed for a number of applications, including to minimize NVH. Suitable for a variety of applications for powertrain, chassis, and the interior and exterior of the vehicle, Saint-Gobain's representatives will demonstrate how the products can optimize component performance for the manufacturer, and the driving experience for the consumer.

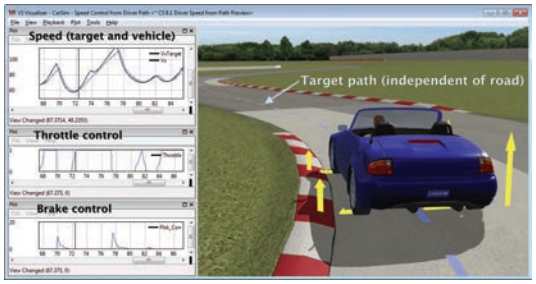
Booth V1165



New features in CarSim

Mechanical Simulation is introducing the VehicleSim visualizer, which uses modern graphical processing units and shape file formats to provide advanced lighting (true shadows, multiple light sources, reflected headlights), highly efficient rendering, rear-view mirrors, and synchronized plotting. Other new features in CarSim include continuously variable transmissions, more options for configuring table-lookup functions, and more scripting in the VS command language. Two significant new features involve the driver model. The target path can be specified completely independently of the road properties, greatly simplifying the import of target lines obtained by GPS on actual roads or racetracks. The target speed can be calculated live using a preview of the road, taking into account the 3D road geometry, along with specifications for driver skill and aggressiveness. Users will also appreciate the new database provided with CarSim, tested to verify that the examples produce reasonable behavior for conventional tests covering full ranges of acceleration, braking, steering, handling, and stability. Three new optional modules are now available: one for more detailed models with effects of engine mounts; one to run with the AVL Cruise powertrain model from within CarSim; and an ITS module to emulate V2V data exchange.

Booth V1377



Advanced driver assistance systems

Reliable recognition of the vehicle's surroundings and traffic situation is the key for advanced driver assistance systems such as adaptive cruise control, traffic sign recognition, lane departure warning systems and parking assistants to function correctly and meet challenges such as higher traffic density and stricter environmental legislation.

Expo exhibitor dSPACE provides tools with the functionalities automobile developers need. The open Simulink-based Automotive Simulation Models (ASM) support the model-based design method for developing driver assistance systems. For example, a comprehensive traffic model enables virtual environments to be created, and various sensor models in the simulated test vehicle detect other road users or lane marks. The traffic scenarios and environment are easily defined via ModelDesk; with its integrated road generator, definition of lanes and other road characteristics is just a mouse click away. Finally, with the new scene-editing features of MotionDesk, the virtual 3D world can now be easily modified. The integration of map-based electronic horizon providers makes the tool chain complete.

Booth 1440 (Automotive Testing)

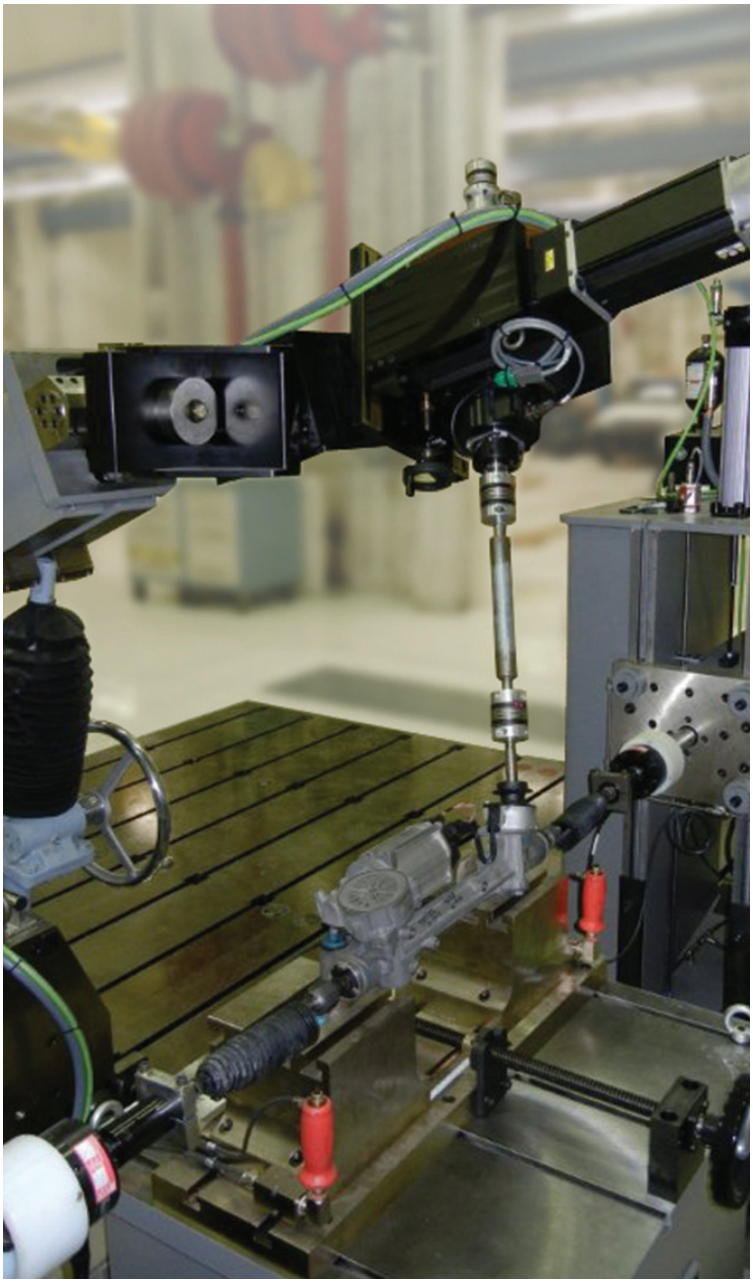
Latest engine compartment DC motors

Fulling & CEIEC – an accredited ISO14001/ TS16949 company – will be exhibiting its new range of engine compartment DC motors, which have been designed with a working temperature of up to 160°C and vibration levels up to 40*g* in mind. The DC motors have been rigorously tested during development to cope with environments associated with a range of applications such as ETC, EGR, WGA including oil, water, and turbo valves. At the expo, the company will also be demonstrating its capacity to design motors to suit specific customer requirements, and showcasing its range of wash pumps for screen wash. These include the patented dual pressure pump, designed to reduce costs for the two-pump format, headlight, and screen wash in one pump body; and to provide a reduction in assembly and electrical harnesses on the car platform.

Booth V1276

COMPILED BY RACHEL EVANS

Accurate EPS testing



RIGHT: **THE NEW MTS HIGH-PERFORMANCE STEERING HEAD MAKES ACCURATE, LOW-TORQUE STEERING EFFORT TESTING A REALITY**

Drivers are more closely connected to the steering wheel than any other part of the vehicle. Through this connection they perceive all the variations and nuances of road conditions, tire imbalance, steering pull and other factors. Steering 'feel' strongly informs the driver's opinion of vehicle performance and overall quality, which is why manufacturers do everything in their power to make sure the steering feels "just right."

Optimizing steering feel requires manufacturers of steering systems and components to carefully and consistently evaluate how drivers interact with their systems on a variety of vehicle platforms. The OEMs set stringent standards, expecting steering system manufacturers to quantify the driver's experience through a battery of steering effort tests.

In the past, these tests focused on high-torque disturbances – the kind associated with sharp turns, lane changes and other familiar maneuvers. With the advent of electronic steering systems, however, maintaining proper on-center feel requires accurate measurement of small-signal torsional disturbances. To do this, inertia and stiffness must correspond to actual vehicle input – a feat that is not possible with current technology.

The hydraulic steer input systems widely used in test labs can't measure low torque magnitudes accurately because they typically incorporate either a commercial torque cell or a pillow block bearing on the output of the torque cell. As a result, the systems exhibit bearing drag torque that exceeds 1.0Nm in most cases, considerably higher than the threshold for driver perception. To make matters worse, slip ring noise, inertia, alignment error, strain gage conditioning noise, and mounting reaction issues all contribute to torque measurement error.

All of these issues are becoming increasingly urgent for steering system manufacturers as electronic steering systems continue to outpace traditional hydraulic mechanisms. By 2014, most vehicle platforms will be converted to electronic steering.

To solve the problem, US-based MTS Systems Corporation has developed a steering head that makes accurate low-torque steering effort testing a reality. The unique design is optimized for low torque measurement, integrating the torque sensor, motor and angle monitoring encoder in a single, compact footprint.

The new steering head minimizes or eliminates measuring error several ways. To eliminate drag and noise, it incorporates a non-contacting digital telemetry coupling. It also substantially lowers the signal noise floor by converting from analog to digital on the rotating shaft and

maintaining digital transmission back to the controller.

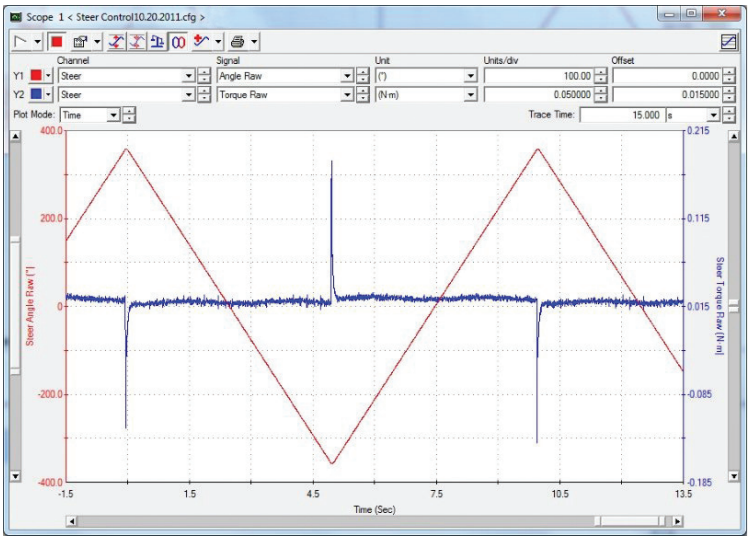
Angle is measured using a high-resolution encoder located at the I-shaft connection point. The system's design also minimizes torsional inertia downstream of the strain-gaged sensor area. There are no coupling alignment issues in the torque cell drivetrain, and there is no measured bearing drag during rotation. In addition, the steering head ensures ample moment rejection without an additional pillow block bearing.

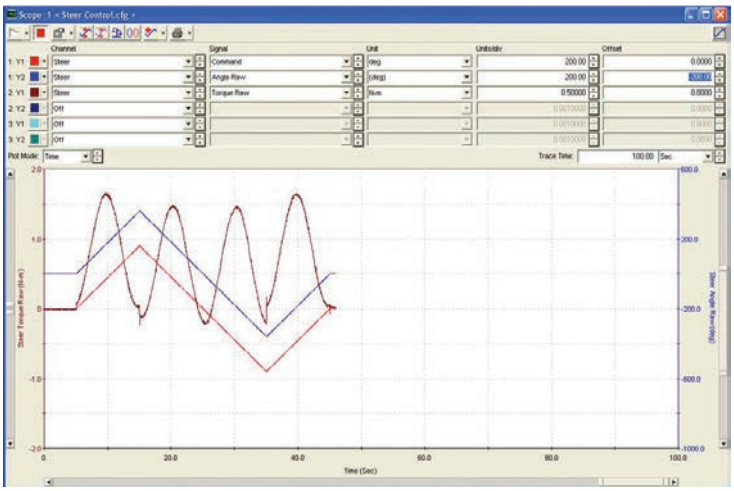
The assembly allows insertion of user-defined torsional compliance while maintaining accurate measurement of the pinion angle and torque. In fact, compliance can be inserted and removed while still connected to the specimen, saving hours of setup time. (A secondary motor angle encoder provides closed-loop angle feedback for this option.)

Similarly, the assembly contains a removable flywheel with user-adjustable inertia, which is positioned behind the strain-gaged area for accurate measurement of both inertial and driving torque. Plus, columns can be attached to the head-mounted support struts, eliminating the need for additional stanchions, brackets or fixtures and their associated alignment issues.

The performance of the MTS steering head exceeds that of any current hydraulic steer input system, and can be customized for higher or lower torque – and higher or lower speed – than hydraulic options. Signal sensitivity is extremely low at 113Nm (with 0.00001347Nm resolution and a noise floor of ±0.004Nm) or 226Nm (with 0.00002694Nm resolution and a noise floor of ±0.008Nm). The maximum speed of the standard 15:1 gearbox is 200rpm.

The overall configurability of the system provides a distinct advantage for test professionals. The handwheel can be engaged at any time, eliminating the need for large rigs of off-the-shelf components that must be reconfigured every time steer input changes. The entire assembly can stay connected to the specimen





while standard test configurations – including rigid drive, no compliance, compliant drive, and no connection to the gearbox from the torque cell – are implemented. All reconfiguration is done at the back end of the unit, which saves time when performing tests that require multiple mechanical configurations for each specimen.

This offering is available with all current MTS steering test systems and can be retrofitted to existing steering test systems from MTS and other providers as long as the control system can accept two incremental encoder outputs and one SSI digital output. The motor command accepts D/A ±10V or current (servovalve) as the source. For most retrofits, fixtures enable the new steering head to drop into an existing positioner assembly, greatly expanding test opportunities.

Steering system and component manufacturers are already taking advantage of the new steering head's low-torque capabilities. Nearly two dozen have been integrated into new MTS steer test systems or retrofitted onto either MTS or competitor legacy test systems.

THE NEW MTS STEERING HEAD (SEE GRAPH, LEFT) **IS APPROXIMATELY 350 TIMES MORE SENSITIVE THAN OLDER, CONVENTIONAL DESIGNS** (SEE GRAPH, BELOW LEFT)**. THE TORQUE SIGNAL ON THE LEFT PLOT, EXHIBITS AN ERROR MARGIN OF 0.005Nm, WHILE THE SIGNAL ON THE BELOW LEFT PLOT, EXHIBITS AN ERROR MARGIN OF 1.75Nm**

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Turnkey simulator

FIGURE 1 (RIGHT): **VI-GRADE'S SIMULATION CENTER**
FIGURE 2 (BELOW): **CORRELATION OF VI-DRIVESIM SIMULATION RESULTS WITH TEST DATA**

"The strategies for developing efficient control systems for vehicle handling and ride are becoming more complex every day, even influencing the conceptual design phase. Unlike aircraft, ground vehicles require continuous driver control. It is becoming essential to assess hybrid test platforms that can provide the driver with real-time perception cues, just as if they came from a real vehicle."

This quote, from a leading European automotive manufacturer, explains the motivation that led to the development of VI-DriveSim, a turnkey solution that provides automotive OEMs and racing teams with a complete set of integrated driving simulators for a new-generation approach to system-level simulation, enabling companies to bridge the gap between virtual prototyping and testing. The VI-DriveSim solution enables users to 'feel' the results of simulations in a totally immersive environment starting from early phases of the development process.

In 2008, VI-Grade initiated a long-term project, VI-DriveSim, with the final objective of offering an off-the-shelf driving simulator solution at greatly reduced cost. VI-Grade identified a team of professional, field-leading partners (*see panel, opposite*). At the same time, the company allocated internal resources to integrate all these technologies within the suite of software solutions it developed internally.

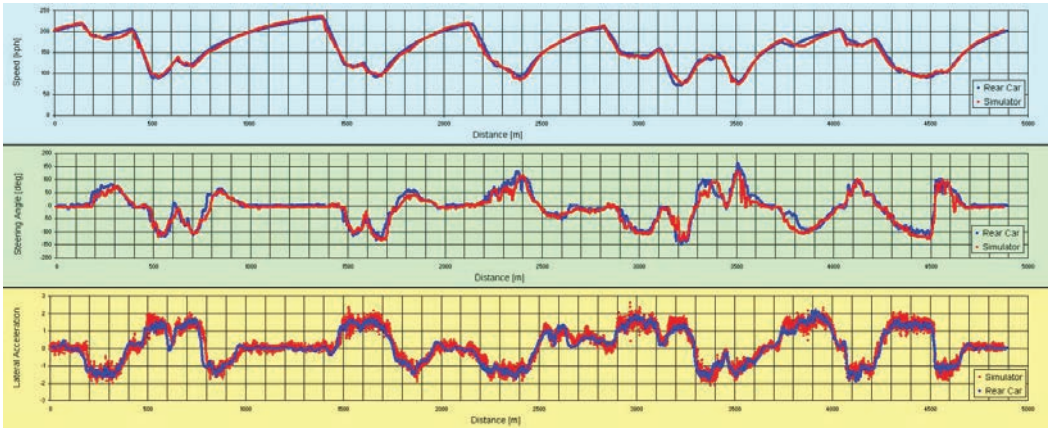
The first prototype of VI-DriveSim was installed at the VI-Grade simulation center for driving simulator technology in Tavagnacco (UD), Italy, at the end of 2010.

VI-DriveSim is an engineering tool that can predict the ride and handling vehicle model response with extremely high fidelity. The solution is based on accurately validated technology through several years of automotive use and can offer an infinite number of vehicle variants performing an infinite number of possible maneuvers, with an infinite number of roads and weather conditions. In addition, all complex vehicle submodels can be integrated into VI-DriveSim by means of block diagrams and/or custom codes, thus permitting the simulation session to go much beyond the limited number of configurations and experiments allowed by a physical prototype.

VI-DriveSim takes advantage of an advanced vehicle model based around the VI-CarRealTime solver, and extensively used in recent years as an off-line simulation tool in the automotive industry.

VI-CarRealTime was originally designed to be the real-time equivalent of the complex and accurate (but non-real-time) vehicle models available through the Adams commercial multibody software. To be computationally efficient, the VI-CarRealTime model uses suspension look-up tables and other subsystem data to populate a simplified and efficient vehicle dynamic model database. VI-CarRealTime quickly solves dynamic equations of motion, while keeping the same accuracy of the parent complex models within the frequency range required for handling and ride dynamics. VI-DriveSim simulations correlate well with track data, as shown in Figure 2, where the red curve is related to simulated data and the blue curve is related to track data.

The same simplified vehicle model can be used by vehicle dynamics and controls engineers to optimize vehicle and control system performance. The model enables users to quickly and easily perform 'design of experiments' campaigns, as well as multi-objective optimization studies, extracting a selected number of models to be submitted to test drivers in order to obtain precious feedback about their 'driver feeling', using exactly the same data file and



VI-DRIVESIM PROJECT PARTNERS

- **VI-Grade for industry-validated real-time vehicle and road model**
- **Concurrent Computing for high-performance real-time computing**
- **SimCoVR for quality graphics and sound**
- **Multimatic for professional vehicle engineering**
- **University of Padua, Italy (department of information engineering), for E&D activities relating to the motion cueing algorithms**
- **Ansible Motion for the development of a desk-side motion platform**

FIGURE 3 (LEFT): **VI-DRIVESIM DYNAMIC PLATFORM WITH RACING COCKPIT**

simulation engine used for offline operations.

Often, the virtual driving session enables the identification of vehicle model issues that require modifications in the original off-line model. Therefore, the human-in-the-loop session can already be performed in parallel with the development of the simulation model. This enables a dramatic increase in the level of fidelity of the simulation model (used across the company for subsystem development, and often exported to external suppliers for their component-based activities), in order to extend its usage to other development areas as well as ride and handling. Once implemented, the complete VI-DriveSim development process could lead to a step forward in the level of confidence that the entire company could derive from simulation.

The strategy used to operate the simulator platform within its limited working space, to provide the driver with the most realistic perception, goes under the name of 'motion cueing'. This is crucial for faithfully reproducing the driver's perception of inertia forces acting on the vehicle. A novel approach to motion cueing design, based on model predictive control techniques, has been developed specifically for the VI-DriveSim project. The algorithm is characterized by two main features: the use of a detailed model of the human vestibular system; and a predictive strategy based on the availability of a virtual driver. Unlike with classical schemes based on washout filters, such features allow better implementation of equivalent-to-vehicle platform motions and tilt coordination to compensate for the missing contributions to steady acceleration, as well as more efficient handling of platform performance limits.

In detail, the prediction model available in VI-DriveSim is driver-adaptive and includes vestibular system dynamics. The prediction is obtained using VI-Driver and/or past telemetry data, and eliminates the unpleasant sensation of acceleration inversion that is often present in systems on which traditional washout filters are used. Additionally, the motion cueing algorithm enables the dynamic platform's performance to be optimized.

By using VI-DriveSim, car makers and racing teams can test a driver's ability to learn tracks or assigned maneuvers, with the ability to add more detailed driver feedback on different car setups.

The adaptation of drivers to the virtual reality of the simulator is an important aspect of the success of VI-DriveSim, and the process has to be developed progressively and with extreme care. When the test drivers become confident about their feelings and have full control of the digital car, the identification process of the vehicle characteristics starts being consistent, and the communication between test drivers and vehicle dynamics engineers leads to a very realistic exploration of the characteristics of all vehicle variants.

The VI-SimCenter features different types of the VI-DriveSim simulator: two static rigs and one on a dynamic rig mounted on a moving platform provided by Ansible Motion. The dynamic platform develops surge, sway, and yaw as serial independent stages. Conversely, for pitch, roll, and heave movement, the machine features a parallel kinematic mechanism, which resembles the coupling among those 3DOF that can be found in a real vehicle. It is important to note that the VI-DriveSim solution is fully scalable, meaning that it is possible to upgrade virtually all components that have already been purchased from static to dynamic simulator recycling.

VI-DriveSim has been tested on several other platform architectures, such as traditional hexapods. The observation was made that the level of perceived realism in the simulator is much more dependent on the motion cueing algorithm than on the platform architecture. Ideally, the mechanical design of the motion platform should be adapted to the intelligence of the motion cueing algorithm.

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Extended simulation

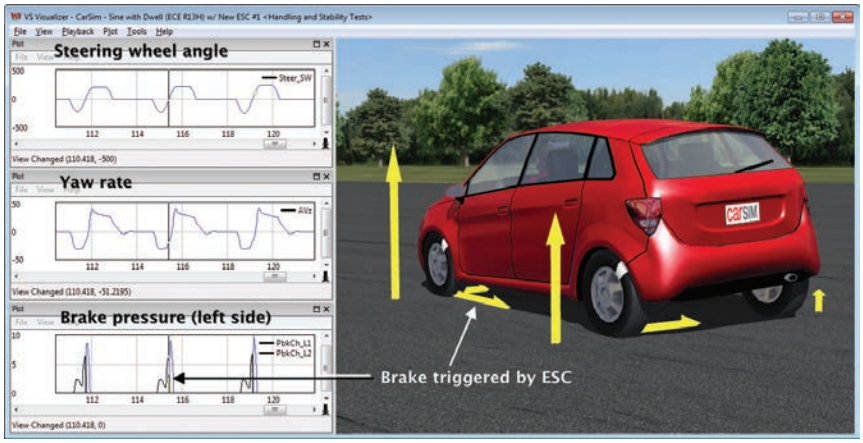


FIGURE 1 (ABOVE RIGHT): **A NUMBER OF MANUFACTURERS USE CARSIM TO CERTIFY ELECTRONIC STABILITY CONTROLLERS (ESC) FOR THE ECE R13H SINE WITH DWELL TEST PROCEDURE**

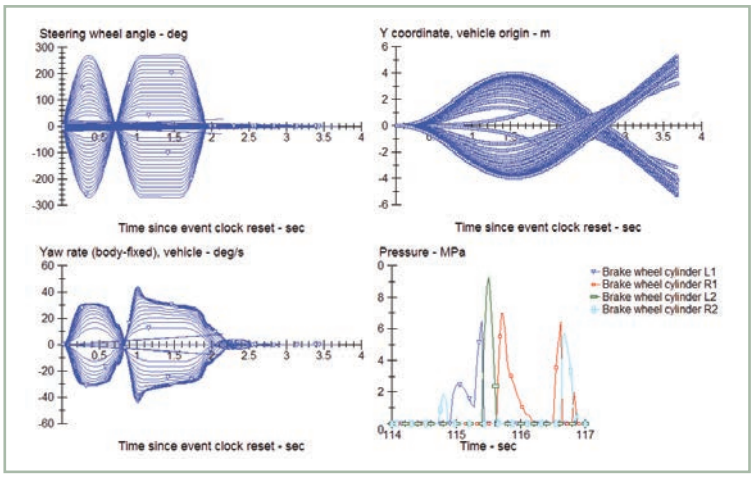
FIGURE 2 (RIGHT): **THE SINE WITH DWELL PROCEDURE INVOLVES REPEAT TESTS WHERE A ROBOT STEERS THE VEHICLE WITH THE SAME WAVEFORM, SCALED WITH HIGHER AMPLITUDE FOR EACH REPEAT**

The current role of CarSim in the automotive industry was not completely anticipated by its creators. The original goal was to define a computer math model that accurately predicts the dynamic response of cars and trucks to driver control inputs. This was to support safety studies involving vehicle braking and stability at a research lab at the University of Michigan.

Early adopters of CarSim were mainly suppliers who needed realistic vehicle models in order to test new controller designs for antilock brake systems (ABS). Other suppliers who wanted to see the effects of their components on the overall vehicle behavior also started using CarSim.

It became clear that a single overall model was not suitable for all existing users. Hence, the simulation architecture was revised so users could extend the software as needed to integrate their custom (and often proprietary) math models with the core vehicle dynamics. The revised software supported different simulation environments: the vehicle model could run with no additional software; it could run under the control of other simulation environments, such as Simulink from The MathWorks or LabVIEW from National Instruments; or, it could run under custom software through an application program interface (API).

With these new options, users could replace parts of the math models with more detailed subsystem models without touching the core vehicle model (unused equations were simply skipped when imported variables were activated). Commercial real-time (RT) systems became available at lower costs, giving suppliers an additional option: to replace parts of the software with actual hardware-in-the-loop using CarSim RT (each CarSim RT version has the core math models recompiled for the associated RT computer and operating system).



As the customer base grew to include manufacturers, research labs, universities, race teams, and other types of users, many cases turned up where the built-in capabilities of the CarSim environment were almost – but not quite – sufficient to cover the intended use. Often, the required extensions to the model were trivial: features such as a few new output variables, or switching between open-loop and closed-loop control during a test, or rescaling an open-loop control for repeated tests, etc. For example, the ESC certification covered by ECE R13H uses a test procedure called 'sine with dwell' (first required in the USA regulation FMVSS 126). In this procedure, a repetitive series of tests is done to demonstrate effective ESC behavior for sudden steering inputs that are designed to cause loss of control in the absence of ESC. The typical behavior for a vehicle with ESC is that the controller will trigger one or more brakes, thereby providing a yaw moment on the vehicle to help maintain control. Figure 1 shows an intervention of the ESC: yellow arrows indicate tire forces, including a braking force at the left-front wheel triggered by the ESC system.

In the sine with dwell test series, the vehicle is steered by a robot controller. First, the robot provides a slowly increasing steering wheel

FIGURE 3: **MULTIPLE TRAFFIC VEHICLES IN A GEELY DRIVING SIMULATOR ARE CONTROLLED BY VS COMMANDS TO PROVIDE A CUSTOM DRIVING SCENARIO**

angle while lateral acceleration is monitored. Several tests are done in each direction (left, right) to determine the steering wheel angle 'A' associated with a lateral acceleration of 0.3*g*. That measured angle is then used to scale a sine with dwell waveform for the robot (see the steering plots in Figure 1 and Figure 2). The yaw rate is monitored to determine the peak value, and to check the instant yaw rate relative to the maximum at two points in the test: one at 1.0 second and one at 1.75 seconds after the steering is complete. At these times, the yaw rate must be less than specified percentages of the peak value, or the vehicle has failed the test. If the vehicle passes the test, it is repeated with the robot using larger steering amplitude. This test is repeated with increasing amplitude until the amplitude is over 270°, then a similar series of tests is done with the steering direction reversed. Lateral tracking of the vehicle mass center is also monitored for the higher steering levels, to ensure that the vehicle was sufficiently responsive to the steering. If the vehicle does not move laterally at least 1.83m (6ft), it fails the test. Figure 2 shows plots for the entire series for a vehicle with ESC that passes the test.

In order to simplify the simulation of complicated test sequences such as sine with dwell, a scripting language called VS Commands is used to define new variables and equations at runtime, and to allow any of the vehicle or control settings to be changed dynamically during a run. For the example ESC testing, new variables were added for the reference steer angle A, the peak yaw rate, and a few other variables. All of the sine with dwell inputs shown in Figure 2 were made using a single waveform with an amplitude of 1°, scaled for each repeat by setting the gain for a table-lookup function based on a multiple of A as defined in the test procedure. Variables in the model are monitored and compared with values calculated from equations specified at runtime to determine when the simulation should switch to another phase of testing, at which time any of the model settings can be changed.

The capability of adding equations and variables at runtime draws on the original technology used to create the first CarSim math models. A symbolic multibody program originally called AUTOSIM was used to generate equations of motion for parametric rigid-body multibody models in a highly optimized form, and write the equations as computer source code. Some of these capabilities were programmed in a library shared by all CarSim math models (as well as in companion products BikeSim and TruckSim). The overall simulation technology is now called VehicleSim (VS), and includes the multibody code generator VS Lisp, the VS command scripting language, and standards for interface (VS API) and communications.

The VS command scripting language has enabled another simulation capability that was never imagined in the early versions of CarSim. CarSim includes up to 99 moving objects that can represent targets for ranging and tracking sensors. CarSim includes options for specifying motions of these objects. However, advanced users have been programming complex traffic behavior using VS commands to add algebraic and differential equations at runtime. For example, Figure 3 shows traffic vehicles in a driving simulator shown by Geely at the 2012 Beijing Auto Show. The motions are keyed to the behavior of the vehicle being driven in the simulator, changing lanes and controlling speed based on interactions with each other and on the position and speed of the driven vehicle.

Now that CarSim is being widely used in driving simulators, many more applications never imagined by the developers will emerge.

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Stabilizer linkages

RIGHT: **POGOSTIK AND HIPERSTIK PORTFOLIO. DIAGRAM** (BELOW) **SHOWS DESIGN IMPROVEMENTS ON THE POGOSTIK**

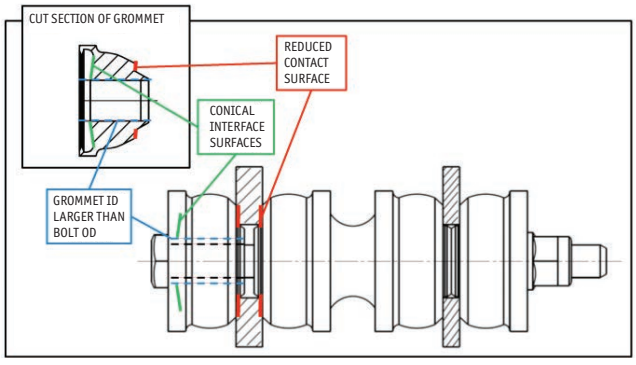
The main objective of a stabilizer link is to hold at a pre-defined distance two chassis hard points that move in different curves. The ball joint plays an important part in many chassis applications, so the attributes of this type of interface are well known. A ball joint has a high axial stiffness and a low resistance toward angular movement (within design limits), but it is complex and costly. A certain failure rate has to be accepted due to an impact-intolerant seal system, a strictly limited range of angular movement, and a high sensibility in terms of the dimensional and surface quality of the chassis hard points.

The reaction of many OEMs to these factors is to attempt to replace the ball joints with bushings. Bushings are more durable and affordable, but they still have a high sensibility toward the attributes of the chassis hard points, and their angular range is highly dependent on the axis of rotation.

In response to this, MacLean-Fogg Component Solutions has developed a unique design for this application: the PogoStik.

The main goal of this development process was not to achieve an even higher performance in terms of axial stiffness and angular flexibility, but to find a design that can achieve the same level of performance, but which is less costly, more durable, and easier to assemble.

For the basic layout, the company decided to go with two axial bushings. With the axis of both interfaces on one line, the whole assembly can be fitted on a single bolt with only one nut needing to be tightened during assembly. The bushings in this layout consist of two separate TPU or rubber grommets per chassis hard point, held at a predefined center-to-center distance by a glass-fiber-reinforced composite spacer. With only rubber or TPU touching the chassis, the PogoStik design is very forgiving to chassis hard-point tolerances and finish.



The main challenge of this layout was its dependency on axial stiffness and angular flexibility. The usual options for increasing the axial stiffness on these type of bushings are a higher assembly preload or using harder grommet materials, but both of these negatively influence the angular flexibility of the linkage. In response, MacLean-Fogg removed material from the outer edges of the grommet surfaces in contact with the chassis hard points (marked red in the drawing, left). Due to the differences in stress distribution between axial and bending loads, this positively influenced the ratio of axial-to-conical stiffness. The grommets were given more space to move sideways by putting a larger hole in the grommet (marked in blue). A conical grommet/spacer and grommet/washer interface (marked in green) allowed the grommets to tilt under bending loads.

This new design offered the customer an axial stiffness close to 5kN/mm, with a bending torque as low as 1.7Nm/° using TPU grommets.

In the meantime, the PogoStik has proved its worth on the road in many chassis systems all over the world, and there is no record of a failed part since its introduction in 2002.

The next logical step was a high-end version of the PogoStik – the HiPerStik (HighPerformanceStik). The design was improved by using the differences in stress distribution between axial and bending loads, in combination with volume effects. In the areas that are mainly stressed by angular movement, the grommet material was replaced with very soft rubber and enclosed with a cup-shaped washer. The result is an axial stiffness above 7kN/mm, with only a slight rise of torque resulting from angular movement to 2.3Nm/°.

With a range of options, MFCS is now able to offer load-bearing capabilities of up to 5kN and a range of angular movement of up to 35° in all directions. The modular design means it can be easily adapted to any center-to-center length.

The large portfolio of grommet designs and materials enables MacLean-Fogg's engineers to adapt the company's products to meet customers' demands.

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automotive testing expo 2012 europe EXHIBITOR

Dynamics test tools

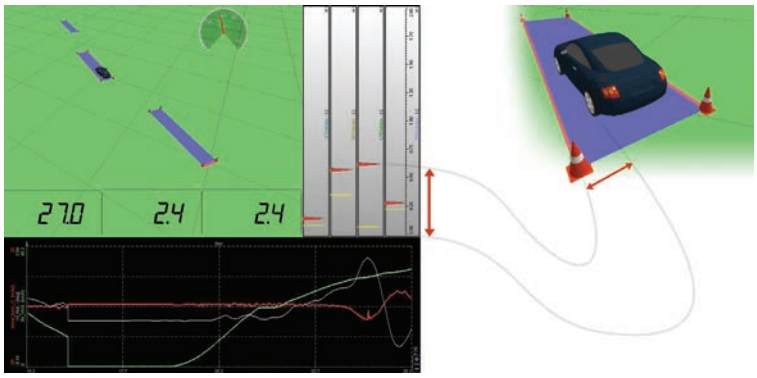
Major automotive manufacturers are using Dewetron data acquisition systems to support vehicle dynamics development, and the new DEWE2 product family extends the power of the test instruments and the range of applications.

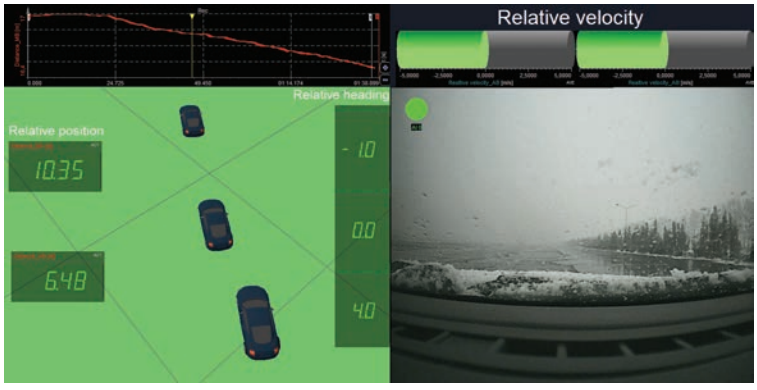
The DEWE2-series data acquisition systems offer increased channel density and are completely modular to support a wide range of different applications in a compact and rugged form. Depending on the sensors and interfaces used for an evaluation, different function modules – such as analog inputs, bus interfaces, and digital or counter modules – can be easily installed into the base unit.

The new plug-and-play feature adds efficiency to the data acquisition system as the hardware can be reconfigured for different tests within one minute, and the system software is the same for all kinds of testing. This flexibility and these new procedures can save the test engineer valuable time. One good time-saving example is cone placement using GPS, which means an ISO lane-change track can be set up in a matter of minutes. An extra advantage is that the cone setup is recorded automatically and is available in the software's 3D virtual track. By keeping the INS/GPS system active during a lane-change test, development engineers get more info than just 'pass' or 'fail' based on falling cones. Now it is possible to determine the exact distance to any cone on the software's 3D track.

SYNC-CLOCK technology ensures synchronized recording of all sensors and sensor systems. Analog signals such as acceleration, temperature, strain, pressure, and force are directly connected to the instruments, as well as CANbus, FlexRay, XCP, GPS, digital states, counters, encoders, and up to four synchronized video cameras. Major sensor systems such as Kistler's RoaDyn 2000 wheel force transducers, or the GeneSys ADMA INS/GPS system are also connected to the clock lines for perfect synchronization.

Having all data automatically synchronized, including video and voice data, makes data analysis and processing faster and easier than ever, and enables editing and analysis times to be reduced by up to 50%. At the same time, the quality of analysis results can be improved significantly.





ABOVE: **DEWE2-SERIES INSTRUMENT.** BELOW LEFT: **ONLINE DISPLAY OF A LANE-CHANGE TEST** BOTTOM LEFT: **ONLINE DISPLAY OF AN ACC TEST WITH THREE CARS**

The new DEWE2-series instruments are also well suited for the evaluation of advanced driver assistance systems. As well as being used for the effective online display of tests, the 3D virtual system also supports driver guidance – on a head-up display, for example. The virtual track guidance eliminates the need for marking tracks on the proving ground, so testing on an icy lake, for instance, can begin with minimal preparation time. If there are two or more cars involved in a test setup, the SYNC-CLOCK technology shows its full potential. Data is recorded absolutely synchronously as the high-precision clock in each data acquisition system is disciplined to the PPS signal of the GPS. The accurately time-stamped data of each car can be transferred over wireless LAN and perfectly matched to the data of the other cars. An online view of the overall situation is always available in the master car (for example, the hunter in an ACC test maneuver).

Dewetron has already supplied more than 10,000 of its DEWE-series data-acquisition systems, and customers all around the world are now benefiting from the DEWE2-series.

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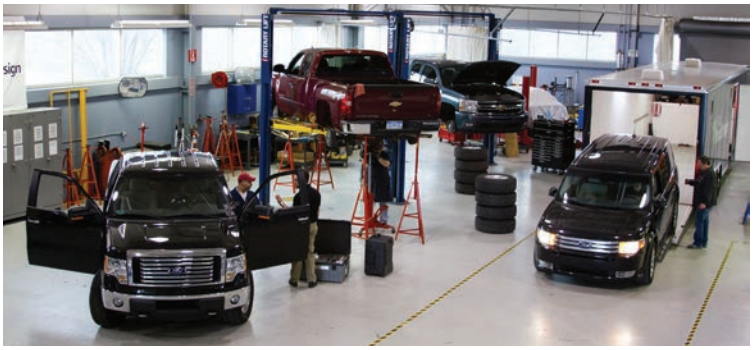
Test and simulation



RIGHT: **THE COMBINATION OF COMPLETE VEHICLE DEVELOPMENT FACILITIES AND BROAD SIMULATION EXPERIENCE BENEFITS CUSTOMERS OF BOTH PRODUCTDESIGN AND HYPERWORKS**

BELOW: **RESULTS FROM MOTIONVIEW/MOTIONSOLVE ARE USED TO PREDICT HOW TUNING OPTIONS WILL AFFECT VEHICLE PERFORMANCE IN THE REAL WORLD**

Everybody knows that time spent at the proving grounds is some of the most valuable effort expended during an entire program. Companies construct prototypes costing hundreds of thousands of dollars to be put through their paces by some of their best engineers at facilities that cost thousands of dollars a day. Plus many hours of technician support and the added travel costs of moving to warm weather facilities when the temperature drops. So how can simulation directly enhance the ability of development engineers to meet aggressive program timelines?

An example regularly employed by Altair ProductDesign (a division of Altair that provides engineering solutions, including physical and virtual vehicle development) is a simulation-driven approach to the creation of a vehicle 'tuning library'. A tuning library is a range of tuning components that the chassis team will use to refine the ride and handling performance of the vehicle during development; it includes everything from spring rates, to stabilizer bar diameters, to bushings.

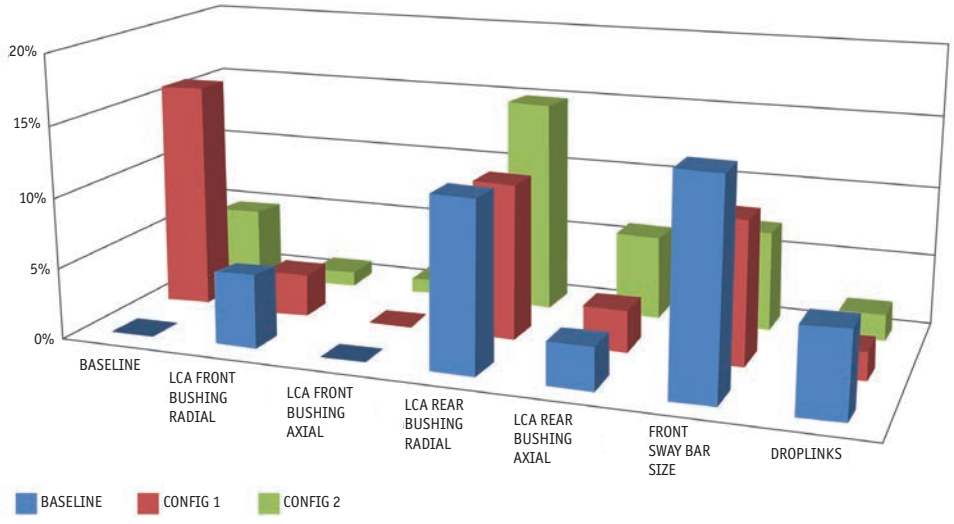
The process begins with the creation of suspension models using a multibody dynamics analysis package, such as Altair MotionView and MotionSolve, which allows engineers to virtually build and analyze almost any chassis configuration. The vehicle model then undergoes a series of static tests, including kinematics and compliance analysis, before completing more complex full vehicle analyses such as constant radius or step-steer testing.

The analysis method mimics the physical development of the vehicle, but allows for hundreds of variations to be explored with instant feedback on the sensitivities of the vehicle to each component. The plot below shows results from a recent sensitivity study, and more specifically how the vehicle's understeer changes as a result of component variations over multiple vehicle configurations. This analysis will be combined with data for roll gradient, ride frequency, steering sensitivity, and other metrics, to not only guide the initial settings of the vehicle, but also to understand the overall sensitivity of component changes before ordering expensive prototype parts or visiting the track.

The analysis results in this example were created with MotionView, part of Altair HyperWorks. Behind the scenes is MotionSolve, an analytical engine that solves issues on positions, velocities, loads, stresses, and forces as requested by the user. MotionView and MotionSolve are capable of representing almost any mechanical system, and the numerous suspension templates, kinematics and compliance analyses, and full vehicle tests make the simulation of an automotive chassis a streamlined task.

While experience will always play the foremost role in vehicle design and development, a well-guided analytical program can also improve efficiency and reduce risk. Today's new alternative energy vehicle concepts present unique packaging, architectural, and weight distribution challenges. Having vehicle development experience along with simulation resources allows the development engineers to gain a better understanding of potential concerns and counter-measures before testing, saving valuable time at the proving grounds.

UNDERSTEER SENSITIVITY ANALYSIS RELATIVE IMPACT



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Suspension bearings

The need to supply efficient automotive components for a range of driving conditions has historically demanded a range of separate solutions. However, enhancements are now being applied to suspension bearing units that can enable single solutions to serve the global marketplace, according to SKF.

In the global marketplace, car manufacturers must provide vehicles that can cope with the wide range of driving conditions found across different territories. Especially challenging is the need to prepare vehicles for the severe conditions that some territories present and the pressure to satisfy this need has placed significantly increased performance demands on the manufacturers of both vehicles and vehicle components, particularly in terms of providing higher reliability and longer operating life.

One way in which to meet such demands is to provide a suspension bearing unit that can support high loads, withstand severe pollution, and improve long-term reliability. The designers and engineers of bearing units have indeed been addressing this need in recent years by attempting to create more compact, lighter systems. In doing so, they have also had to ensure that any developments in suspension bearing units allow the flexibility to integrate with surrounding components, as well as balancing cost with function so that units that can be manufactured for optimized value – an essential consideration if the units are to be widely used.

Historically, suspension bearing units have been produced for specific environments, but now global platforms require solutions that suit different environments. For manufacturers, meeting this challenge can yield very positive results, since a successful solution for a global platform reduces the need to design separate solutions for multiple customers and regions. For users, an enhanced suspension bearing solution for a global platform is also a great benefit, since it has the potential to improve a car's ride comfort (especially for vehicles belonging to the C segment upward), increase controlled friction torque, and reduce undesirable vehicle noise.

To achieve such enhancements, designers and engineers have looked at several components within the suspension bearing. Improving seals, for example, is a key challenge, since increasing the ability of suspension bearing units to withstand extreme levels of external pollution depends greatly on providing a high standard of sealing. Another key requisite is increased strength, and this has led to a re-examination of ball sets in order to increase radial load capacity.

SKF's own innovations in this field led to the launch of the robust MacPherson suspension bearing unit (MSBU), which can be used within a wide range of automotive applications. The unit features an innovative seal design, which combines excellent protection against external pollution with low friction torque. A new ball set was introduced to increase radial load capacity by 20%, while reducing radial clearance by 40%, and a metallic spring seat was incorporated. This is over-molded inside a lower polymer housing and increases resistance to deformation by up to 50%, as well as stress levels on composite components by around 8%. This new design of bearing unit offers even greater operating life, helping to improve the reliability of suspension systems.

By taking advantage of such enhancements in suspension bearing units, manufacturers can produce vehicles that are not compromised by the high levels of friction that result from bad sealing solutions and inadequate ball set design, or by the deformation that results from the poor design of spring seats. In doing so, they can meet the increased performance demands presented by severe driving conditions, while supporting high loads and improving long-term reliability. Not only can this design evolution reduce the need for a series of individual solutions, it can also offer the end-users the benefits of improved suspension bearing design in a variety of vehicles.

ABOVE: **THE MACPHERSON SUSPENSION BEARING UNIT, DEVELOPED BY SKF, PROVIDES IMPROVED RELIABILITY OF SUSPENSION SYSTEMS**

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automotive testing expo 2012 europe EXHIBITOR

Slip angle measurement

RIGHT: **VBOX 3ISL AND VBOX FILE MANAGER.** BELOW: **ANTENNA POLE MOUNTED ON A VEHICLE**

Racelogic has recently made what it terms a "huge breakthrough" in dual-antenna GPS technology, with the release of the VBOX3i Dual Antenna GPS/GLONASS logger. By using two GPS engines configured in a 'fixed baseline RTK setup', the company, based in Buckingham, UK, claims the new system combines high accuracy and test repeatability with the ability to measure slip and pitch/roll angles at 100Hz.

Achieved by taking measurements from both GPS and GLONASS constellations using a new breed of satellite antenna, the system is so accurate that at 2.5m separation the system measures slip angle to an accuracy of 0.04° rms and pitch angle to an accuracy of 0.028° rms.

Furthermore, it can even detect the difference a side wind makes to the slip angle measurement of a moving vehicle – a feature that even the best inertial systems cannot currently replicate.

Racelogic's managing director, Julian Thomas, says, "For the first time, slip and pitch/roll angle measurements are available at 100Hz with no drift and extremely low latency. Combining our highly popular product for non-contact speed and distance measurement – the VBOX3i – with the ability to measure slip and pitch/roll angles, the new VBOX3i Dual Antenna is our most powerful GPS datalogging system ever.

"Giving test engineers the ability to capture true heading, slip angle, pitch angle, yaw rate, lateral velocity, and longitudinal velocity at 100 samples per second, alongside logging distance to within 2cm accuracy, the new system is ideal for brake testing, dynamic tests, and steady-state cornering."

The new package now comes with Racelogic's VBOX Manager as standard, which gives users the ability to control the dual-antenna functionality, remotely configure antenna separation, externally switch the parameters logged, and automatically calibrate the offsets for pitch/roll and slip.

Connecting via serial, USB, or Bluetooth to a laptop/tablet PC, or recording directly to a compact flash card, engineers can view results in real time or in post-processing mode using VBOX Tools – a data-analysis software package that comes with all VBOX systems.

The VBOX3i Dual Antenna includes four high-resolution analog input channels capable of sampling and logging external sensor voltage signals at 500Hz – making it ideal for ECE 13-H Brake Assist System testing – and two CANbus interfaces to allow connection of Racelogic's input modules, while transmitting GPS data on the second CANbus.

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VEHICLE DYNAMICS EXHIBITOR EXPO 2012

Chassis systems expertise

In the two years since BWI Group became an independent company, it has acquired a global reputation as a leading supplier of premium chassis systems. The product portfolio is split into two complementary groups: ride and handling technologies, and braking technologies. In both areas, the offering ranges from high-quality volume items such as twin-tube dampers and brake system components, through to highly sophisticated active systems and the expertise required to integrate them with high-end vehicle programs.

The company believes that it is the only major supplier to offer a range of technologies in both damping and braking, giving it a unique capability as increasingly sophisticated electronic controls allow tighter integration of vehicle systems. With an extensive in-house electronics capability and substantial vehicle-level experience, BWI can deliver complex, integrated solutions reliably and quickly in any region.

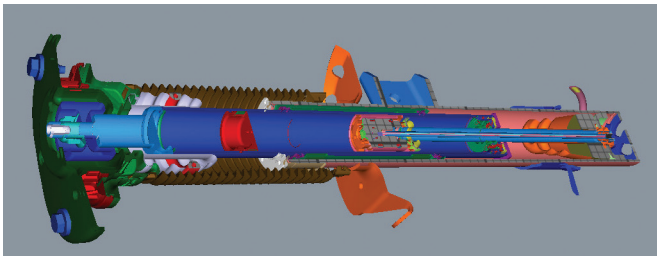
It's a capability that is in increasing demand. As vehicles acquire a growing range of sensors and an increasing ability to share data between systems, the benefits of tighter integration are increasing. BWI products are building on these opportunities by offering compatibility with open architectures and a modular structure that takes time and cost out of development programs.

At a component level, BWI's strategy of delivering a comprehensive, well-supported portfolio in each of these sectors allows simplification of a vehicle manufacturer's engineering, purchasing, manufacturing, and logistics. Simplification is increased by the high level of electronic configurability, allowing broad model ranges and global platform strategies with minimum impact on complexity.

BWI'S PRODUCT PORTFOLIO

- **Adaptive powertrain mounts**
- **Monotube dampers/struts**
- **Twin-tube dampers/struts**
- **MagneRide ride control system**
- **Coil springs**
- **Air suspension**
- **Corner and axle modules**
- **Brake components and assemblies**
- **Friction components**
- **Brake control systems**
- **Brake apply systems**
- **Electronic stability systems**
- **Roll-control systems**
- **Systems integration**

The belief that complication must be minimized is reflected in the design of all BWI systems, which demonstrate the ability of successful innovation to deliver the best-possible performance using the simplest, most elegant technologies. An excellent example of this is MagneRide, which is widely recognized as one of the world's most advanced production ride control system. Using fixed-orifice dampers whose response can be changed by electromagnetically 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.



BWI CHASSIS PRODUCTS: ADAPTIVE POWERTRAIN MOUNT (BELOW LEFT)**; ACTIVE STABILIZER BAR SYSTEM** (BELOW CENTER)**; RANGE ROVER EVOQUE'S MAGNERIDE DAMPER** (ABOVE)

MagneRide illustrates BWI Group's strategy of applying robust innovation to solve each customer's unique challenges at an affordable price, whether that requirement is to deliver groundbreaking dynamics, or to simplify vehicle assembly. Combined with the company's in-depth electronics capability and vehicle-level integration expertise, it's also the strategy that will help vehicle manufacturers take the next step, further improving dynamics, refinement, and safety by building on the growing synergies between vehicle systems.

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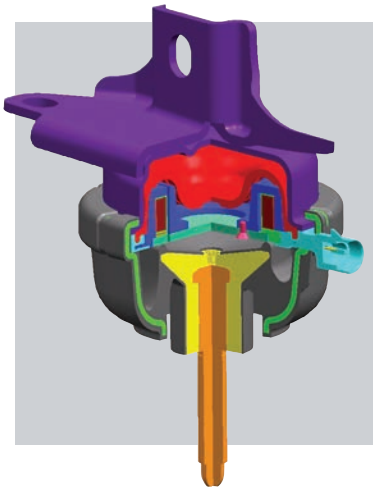
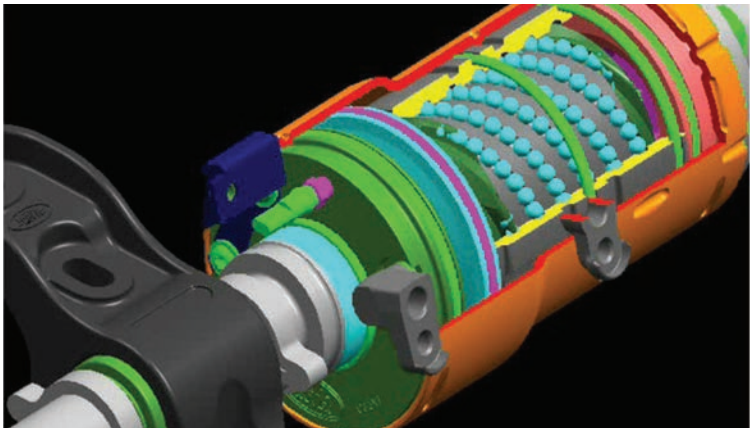
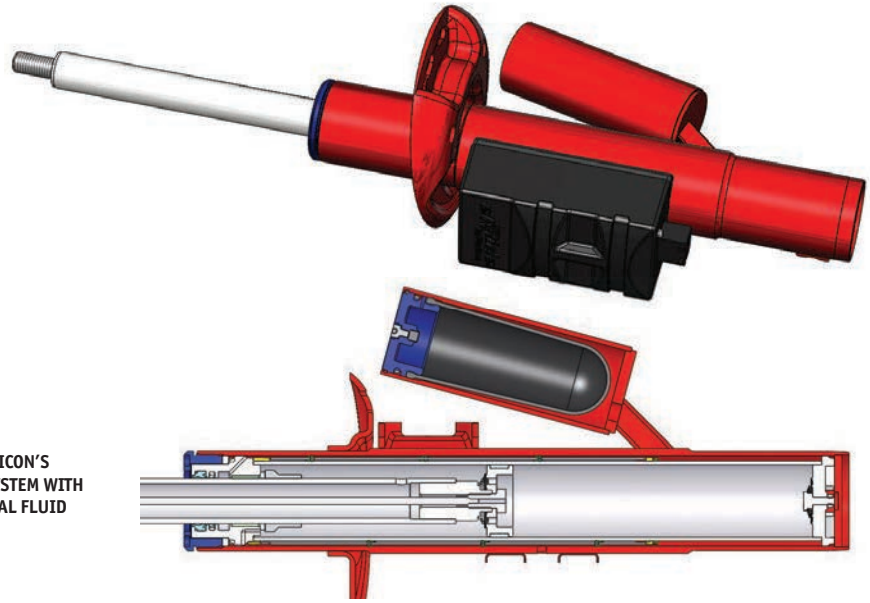




VEHICLE DYNAMICS EXPO 2012 SPEAKER

Fast, efficient damping



TWO VIEWS OF FLUDICON'S ERRIDE DAMPING SYSTEM WITH ELECTRORHEOLOGICAL FLUID

Modern chassis systems continuously regulate each wheel to reach an optimum in terms of comfort, handling, and safety. The eRRide damping system with electrorheological fluids, developed by Fludicon GmbH, works with control periods up to 1ms and is thereby measurably quicker than common valve-based systems. Furthermore, the intelligence for the appropriate characteristic has been transferred to the individual dampers, eliminating the need for a central control unit.

The latest adaptive damping systems, which work predominantly with proportional valves, are very costly in terms of production and assembly, and are found in the upper price segment. Furthermore, the attainable control times are not suitable for all applications.

A very efficient and cost-attractive solution is offered by Fludicon, which develops and produces damping systems using an electrorheological fluid. This fluid, trade-named RheOil, is a dispersion of carrier liquid and polarizable polyurethane particles. They have a diameter of about 5µm and are formed as dipoles. On application of an electrical field, polymer chains are formed, leading to a constriction of the flow cross-section and thereby increasing flow resistance within the damper. The required increase is repeatable any number of times. The unique character of this technology is the rapid change in the fluid flow property allowing for adjustment within milliseconds – whether for damping, vibration reduction, or positioning.

The eRRide damping system with electrorheological fluids developed by Fludicon offers an optimal chassis control system for a wide range of different vehicle segments.

The latest generation of this damping system transfers the intelligence for the appropriate characteristic via miniaturized electronics into the individual dampers – this is the digitizing of hydraulics. It therefore functions without a central ECU. The control system, which works with (IP-protected) real-time algorithms, sets the damper forces at the four wheels each millisecond, thereby optimizing driving comfort and safety.

The outstanding property of eRRide is its fast control right up to 1ms. By interacting with other comparably fast-regulating electronic systems such as ESC or ABS, a response to driving situations can be achieved that was not previously possible, for example in sports cars or motorcycles, where extreme driving maneuvers are often needed within split seconds. This control period is substantially shorter than with valve-based adaptive systems. The eRRide damper is also quicker than magnetorheological systems, where the damping is regulated by changing magnetic field strengths.

Furthermore, the higher turn-up ratio of electrorheological dampers at lower damping speeds, compared with valve-based alternatives, means they can be efficiently used in both light- and heavy commercial vehicles.

The RheOil fluid is characterized by a high hydraulic stiffness, low density, and low temperature dependence, and is the world's only electrorheological fluid to fulfil the requirements in the automotive and industrial sectors: low base viscosity, no abrasion, as well as good lubrication properties and material compatibility. For this reason, Fludicon's electrorheological dampers are also constructed with standard damper materials (seals, guides, surfaces).

Another advantage over valve-based systems is the setting of the damping forces via viscosity changes. This reduces investment costs as precise and thereby expensive valves are no longer needed. Even the design of the electrorheological damper is extremely simple, reducing manufacturing and assembly costs. On the subject of safety, it is important to note that this solution ensures a so-called basic damping during supply voltage failure. Electrorheological dampers work noiselessly and are therefore ideal for application in electric and/or hybrid electric vehicles.

The electrorheological damper also reduces the rolling resistance that occurs due to road bumps, and so addresses the requirement to decrease fuel consumption and CO_2 emissions. In addition, there is a reduction in wheel load fluctuations, which reduces tire wear and protects the road. This is especially true for vehicles with higher wheel loads such as heavy-duty trucks.

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VEHICLE DYNAMICS EXHIBITOR EXPO 2012

NVH improvements

Increasingly, consumers worldwide are selecting vehicles based on performance and safety requirements rather than cost. In this climate, manufacturers are optimizing powertrain and steering systems to balance consumer and European regulatory demands for performance and sustainability, in order to thrive in a very competitive market. Composite bearings and tolerance rings play a key role.

Composite bearings are designed with a layer of self-lubricating polytetrafluoroethylene (PTFE), which controls friction between two moving parts, saving energy by facilitating movement and to absorb noise, vibration and harshness (NVH) before it is transmitted to the chassis and powertrain.

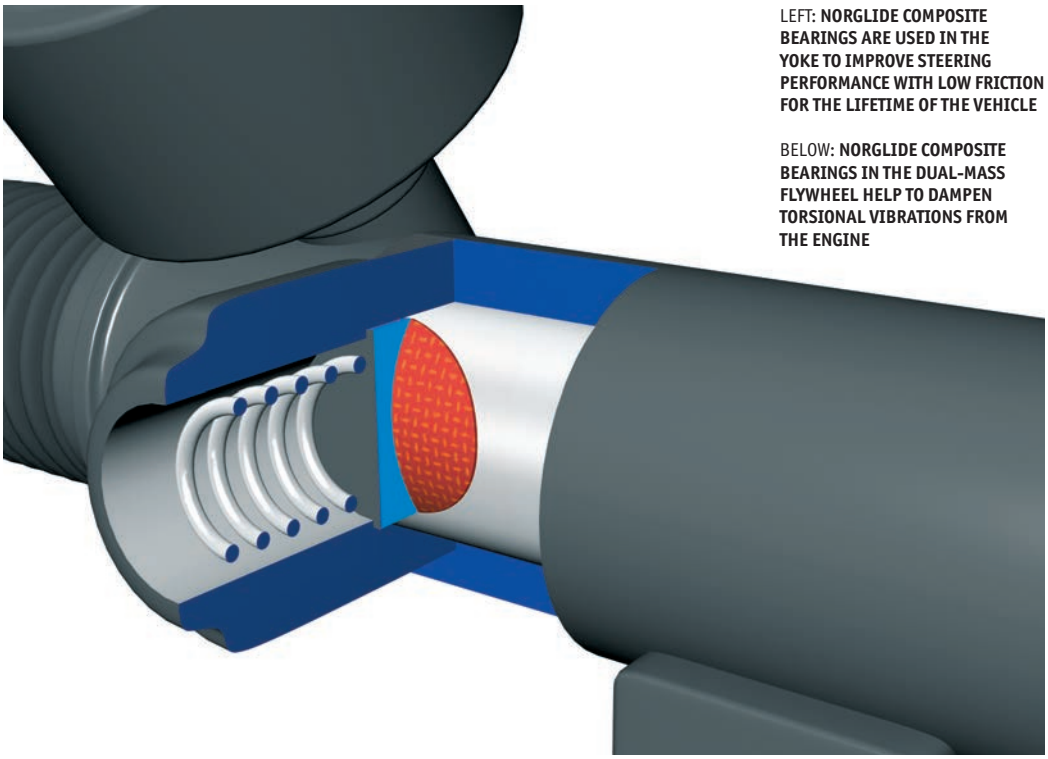
Tolerance rings are high-quality steel, radially sprung fasteners that allow for optimal joining between two annular (ring-shaped) components. The key feature of a tolerance ring is the protrusions that run around its circumference, which, like the composite bearing, effectively absorb NVH that is transmitted through the mechanical joints within chassis and powertrain applications. The friction control and NVH reduction offered by both components can improve overall performance of mechanisms and driver experience.

Composite bearings and tolerance rings are used in chassis applications to improve driver feel, control friction and reduce NVH over the lifetime of the vehicle. For example, the thickness of the PTFE layer and modified design of the NORGLIDE composite bearing when used in the steering yoke enables the load to be evenly distributed. This reduces friction, improving the driving feel and response of the steering system, while enhancing its lifecycle.

Thanks to advances in technology, powertrain components have been developed that offer improved NVH reduction to maximize vehicle performance and enhance the driving experience for motorists, particularly with regard to the dual-mass flywheel. The dual-mass flywheel dampens torsional vibrations from the engine to prevent them reaching the gearbox, resulting in a more comfortable driving experience for the motorist, even at low engine speeds.

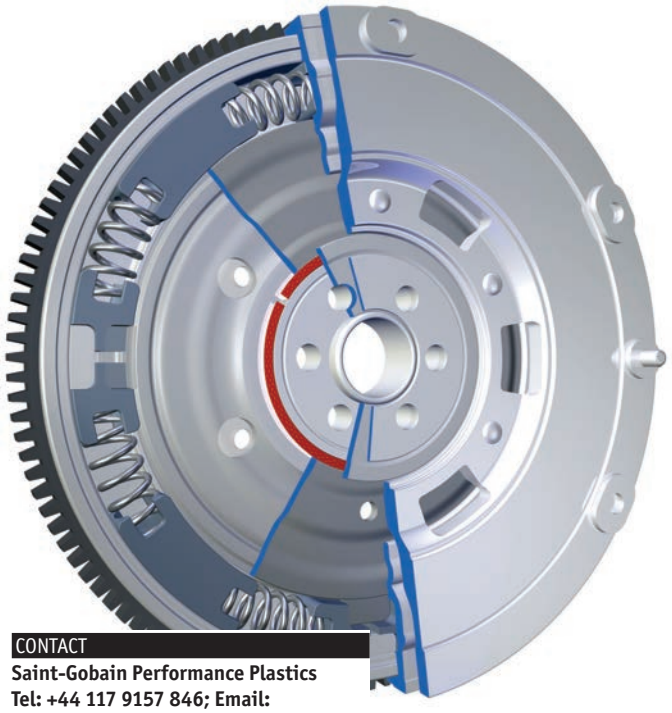
The trend towards "downsizing" engine components, such as reducing the number of cylinders, can actually increase the intensity of torsional vibrations. To combat this, manufacturers now use PTFE-coated composite bearings in the dual-mass flywheel. The low friction values offered by the PTFE and the internal structure of the composite bearing, designed to perform under both axial and radial stresses, have led to improved NVH reduction compared with previous models.

The market trends of recent years are clear and look set to continue well into the future. The demand globally is for high-quality vehicles that are affordable, yet meet performance demands. With innovative components, manufacturers can respond to these global trends without compromising on quality or cost.



LEFT: **NORGLIDE COMPOSITE BEARINGS ARE USED IN THE YOKE TO IMPROVE STEERING PERFORMANCE WITH LOW FRICTION FOR THE LIFETIME OF THE VEHICLE**

BELOW: **NORGLIDE COMPOSITE BEARINGS IN THE DUAL-MASS FLYWHEEL HELP TO DAMPEN TORSIONAL VIBRATIONS FROM THE ENGINE**



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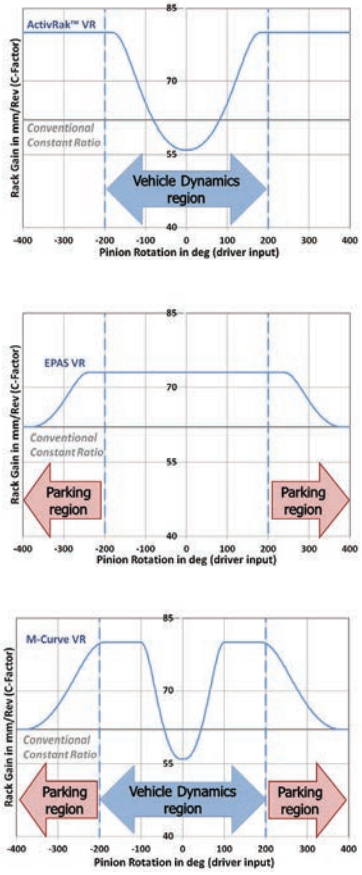
Variable ratio steering

RIGHT: **EXAMPLE OF AN ACTIVRAK MECHANICAL VR STEERING RACK**

The market for variable ratio (VR) steering racks is continuing to rise, according to David James from MVO GmbH.

"Growth in the market for VR racks has two main drivers," he says. "On the one hand, we see increased demand for enhanced steering with respect to vehicle dynamics. This tendency started with the introduction of 'active steering' systems in the past 10 years – this is an expensive solution for the premium market, but it has generated a greater awareness about steering and what is possible. The mass market needs a simpler solution – the use of mechanical VR racks such as our ActivRak, together with 'smart' EPS systems, gives a solution with 90% effect for less than 10% additional cost." Such racks are used on 'direct' or 'progressive' steering systems, offering relaxed high-speed driving with fast kinematic response.



RIGHT: **THE THREE PLOTS SHOW RACK GAIN IN MM/REV (C-FACTOR) VERSUS PINION ROTATION (°). THE** TOP GRAPH **SHOWS THE CURVE FOR THE ACTIVRAK VARIABLE-RATIO RACK; THE** MIDDLE GRAPH **IS FOR AN EPAS VR SETUP; AND THE** BOTTOM ONE **IS THE 'M-CURVE VR', WHICH COMBINES THE TWO**

"On the other hand, there is the size and cost of servo-assistance motors and controllers used in EPS," continues James. "There is a global tendency for lower (more direct) steering ratios, leading to increased rack gains and therefore higher rack loads. An alternative to using larger assistance systems is the use of mechanical racks with so-called EPAS VR to reduce the power requirement during parking. Such a solution can also help with 'park assist' features, where the torque from the driver must also be replaced by the system. The current cost trend for rare earth metals makes downsizing power packs more attractive."

These two technologies are, however, not mutually exclusive – the two are readily combined with an 'M-Curve VR'. "About 50% of the rack development we do uses an M-Curve – it's a natural progression," he says. "There are some exciting solutions coming onto the market in the next two or three years."

Increased demand is being matched by new capacity. MVO has just commissioned its first Bishop warm forging cell for the production of variable ratio racks, one of the first investments following the purchase by MVO's holding company of the Bishop Steering Technology group of companies in January 2011. Currently busy producing validation parts for the first projects, production commences in the last quarter of 2012, and capacity can be expanded to about 1.2 million racks, which can be offered to steering manufacturers around the world. "Our customers are predominantly the steering gear manufacturers who do not have their own variable-ratio manufacturing capability," says James.

A sister company of MVO is Austria-based Stahl Judenburg GmbH, one of the leading manufacturers of bright steel in Europe. The company develops specialized materials for the manufacture of steering racks and other high-performance components, and is currently a leading supplier of steel for rack drive and dual pinion racks.

The integration of Stahl Judenburg, MVO, and the Bishop companies results in the ability to cover the entire value chain from the design of a steering rack by Bishop, development of the required steel by Stahl Judenburg, to the fabrication of steering racks by MVO and Bishop in Indianapolis. This close collaboration combines competence in design, materials, and production, and guarantees benefits in the field of steering systems for customers all over the world.

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VEHICLE DYNAMICS EXHIBITOR EXPO 2012

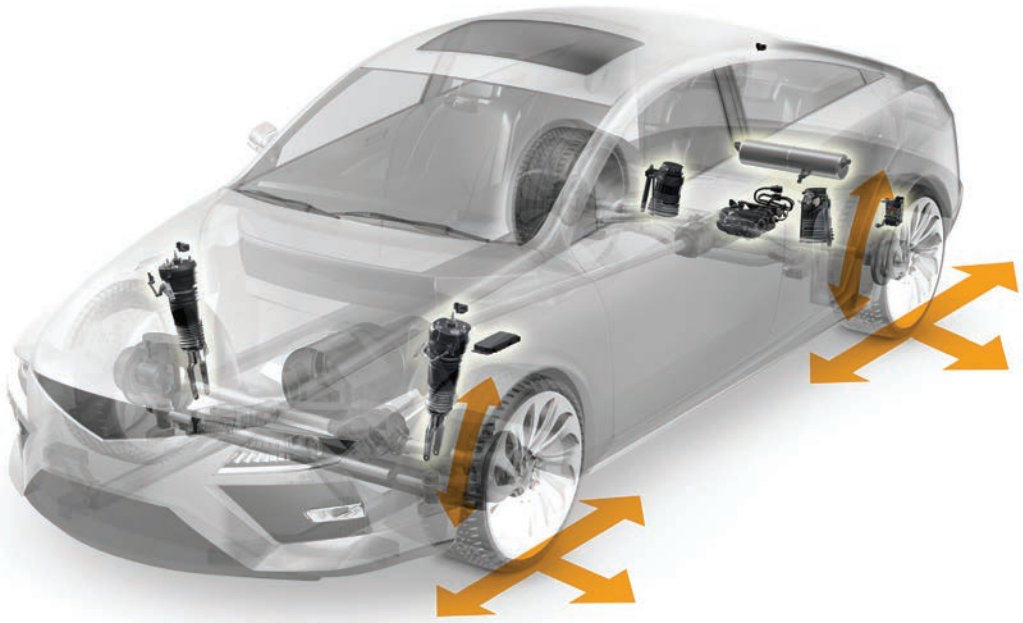
Electronic air suspension

The electronic air suspension (EAS) system represents an important step in the development of chassis technology. With its electronic possibilities, plus the introduction of cost- and weight-optimized components in combination with intelligent bellow technologies, international automotive supplier Continental has created a chassis for the future, providing the driver with a high level of safety, plus comfort and sportier handling.

EAS automatically adjusts damper and suspension levels, as well as vehicle height, to different driving conditions and load changes, thus offering a reduction in rolling and pitching, and an additional increase in movement, a reduction in wheel load fluctuations, and a noticeable increase in dynamics and comfort.

Its efficiency is the result of the link between EAS, ESC, and the electronic steering control. Sensors coupled with the electronics of the various systems create conditions for perfect interplay, even in critical driving situations. With innovations such as integrated valves and supplementary volumes, high-comfort air-spring bellows, closed air control units, scalable electronic control units, guided air-spring modules, and new functions such as easy entry or easy loading, Continental is developing technologies that combine safety with driving pleasure. EAS also helps to reduce fuel use and emissions.

Continental, as a manufacturer of air suspension systems, is able to produce all the system components in-house, apart from the shock absorbers. The company's portfolio includes complete air-spring systems, modules, and components, as well as modules and components for electronic steel-spring systems for all types of cars, vans, SUVs, pick-up trucks, and commercial vehicles.



ABOVE: **AIR SUSPENSION SYSTEMS AUTOMATICALLY ADAPT DAMPING AND SPRING CHARACTERISTICS, ALONG WITH THE VEHICLE'S BODY LEVEL, TO CHANGING DRIVING CONDITIONS AND LOAD CHANGES**

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JOHN HEIDER CONSIDERS CUSTOMER APPRECIATION OF VEHICLE DYNAMICS TECHNOLOGIES

"It's doubtful that anyone will answer 'fuel economy' when asked what they like most about their steering"

As much as it pains me to write these words, our beloved world of vehicle dynamics and chassis engineering gets no love from the majority of the buying public. This is nothing new. Ask anyone who has feverishly worked on active suspension systems, active roll-control systems, four-wheel steering, steer-by-wire, brake-by-wire, or numerous other chassis technologies destined to become the next must-have feature. Have all these technologies made it into production? Absolutely – both successfully and unsuccessfully – and usually in spite of the kicking and screaming objections of finance departments being forced to swallow the costs by omnipotent product development heads. But do the customers understand how these technologies alter their driving experience? Well, that's a difficult question – let's look at a few examples.

Suppliers began to demonstrate commercially viable, fully electric power-assisted steering (EPS) systems in the mid- to late-1990s, with a myriad of advantages touted: less complexity, easier to tune, cheaper, better package, inherent variable assist, improved warranty, and improved fuel economy, among others. With a list of advantages like that, what could possibly delay immediate and swift adoption? Well… cheaper turned into more expensive, easier to tune turned into more complex, and overall steering performance and feel was not able to match that of a hydraulic system. Without the legitimate advantage of improved fuel economy brought to the forefront by ever-increasing fuel prices and government CAFE mandates, these systems would still struggle for adoption by those OEMs concerned about ultimate steering performance. The latest EPS offerings from BMW, Ford, VW, and others, are very good and light years ahead of the systems of even three years ago. Torque sensing, the fidelity of calibratable parameters such as hysteresis and friction, overall system stiffnesses, and other characteristics, have been continuously improved. In the eyes of the buying public, most current EPS systems are very acceptable, although it's doubtful anyone will answer "fuel economy" when asked what they like most about their steering. Now ask an experienced steering evaluator to assess their favorite EPS vehicle today with the most recent comparable hydraulic vehicle and listen to their response…

Continuously variable damping control has also traveled a long road from initial viability to mainstream production. From two-position, manually switchable dampers in the early 1980s that simply changed a bleed orifice to today's systems of extremely fast-acting solenoids or MR fluid dampers… most major OEMs have experimented with these systems at one time or another.

Manually switching between a system's highest and lowest damping settings on a pre-selected road surface will convince any skeptic of the system's tremendous capability. Yet despite the technical capability of these systems, the reality is that they are expensive, difficult to develop, and add more cost and complexity to a vehicle's electrical system. Get the development right and you have comfort and control advantages; get it wrong and you have added tremendous cost to your vehicle and provided reduced functionality versus passive dampers.

It would be nice to think that these systems could have been implemented on their own technical merits, but the reality is that sales and marketing departments at the luxury OEMs have played a major role by supporting any content addition that allows them to keep up with or surpass the competition. The customer has more menus to choose from on his vehicle interface screen, but is it clear to him whether his vehicle has been improved or not?

In the future, the majority of the buying public will still have a somewhat lackluster view of vehicle dynamics and chassis innovation. But the advanced projects of today have a tremendous advantage over those of years gone by; namely the ability to integrate multiple technologies and deliver something every customer can appreciate, but hopefully will never have to experience – unsurpassed levels of active vehicle safety.

Imagine next-generation stability control systems interacting with forward radar sensing, active front steering, active braking, adaptive dampers, active roll control, active differentials, and advanced GPS systems. Will the customer be excited about any of these technologies or be able to explain how he possibly avoided a massive accident? Of course not – we'll just let him think it was his superior driving skills…

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

ADAPTIVE DAMPERS DON'T ALWAYS RESULT IN A VEHICLE THAT'S MORE APPEALING THAN A PASSIVELY DAMPED ONE

ON THE WEB

Further comment from Heider at vehicledynamicsinternational.com

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CASE 4: FERRARI CALIFORNIA, BY GRAHAM HEEPS

SPECIFICATIONS

Ferrari California
Dimensions: 4,563mm (L) x 1,902mm (W) x 1,308mm (H)
Wheelbase: 2,670mm. Track: 1,630mm (F), 1,605mm (R)
Curb weight: 1,735kg
Suspension: Double-wishbone (F), multilink (R). BWI MagneRide damping, optional fit: £3,199
Brakes: Brembo carbon-ceramic. Discs 390 x 34mm (F), 360 x 32mm (R)
ABS/ESC: Bosch/Ferrari
Steering: TRW
Tires on *VDI* test car: Pirelli SottoZero W240 245/40 R19 M+S (F); 285/40 R19 M+S (R)

Regular readers will remember that my first encounter with a Porsche 911 (albeit one with an inappropriate spec) ended in disappointment. Surely my first Ferrari wouldn't prove to be similarly iconoclastic?

I've never particularly cared for Ferrari's recent moves to cultivate a 'luxury brand' – I'd take Alberto Ascari's lucky helmet over an overpriced baseball cap any day of the week. Fortunately, by common consent, the quality of its road cars appears to be inversely proportional to the subtlety of its marketing.

Some people have dismissed the car as a 'soft' Ferrari, one for posers not *piloti*. Indeed, Ferrari has just introduced a Handling Speciale package for drivers seeking "a more dynamic" driving experience.

But I say they're missing the point. This car is ridiculously usable in everyday driving, at legal speeds, which is where over 90% of us spend our time behind the wheel.

Leave the F1-style manettino switch in 'Normal' and you'd be fooled into forgetting this was a 453bhp, 192mph supercar. The driving position is brilliant, the seats super-comfy, and the folding hardtop seals superbly for quiet cruising. The throttle response is immediate, without being too snappy, or too lazy like a Porsche in its default setting. The twin-clutch box takes care of gearchanges unobtrusively, even if it takes a minute or two to warm up. Thanks to the engine's front-mid location, the turning circle is very practical – about the same as a Ford Mondeo. The MagneRide-enhanced ride is very, very good for a car of this type, better than some executive cars, but the winter tires fitted to our test car will have done the California a favor in this regard.

Negatives? I'd have preferred a little less heave, even at low speed, over my local hump-backed bridge, and I'd remove a bit of assistance from the over-light steering, too.

I drove the California as I would any other vehicle: to work and back, on the school run, and for family outings with two small children wedged in the rear 'seats'. But this isn't any other vehicle, or more to the point, any other engine: when you open the throttle at low revs there's a rumble from a very deep place that can't help but put a smile on your face. And as the revs rise through the power band, it turns to a proper, Italian, V8 howl that leaves you giggling like an idiot.

To help reduce CO_2 emissions to 270g/km, Ferrari thoughtfully offers an optional Stop&Start system for when Ocean Drive gets gridlocked. It works as well as any of the mainstream systems I've tried. But inevitably, such a pleasurable powertrain doesn't come without pain, and our average fuel economy of 17mpg in mostly gentle use is still short of the claimed combined consumption figure of 24.5mpg.

Further pain on the wallet is inflicted by the price: £147k list, plus £55k of options and accessories fitted to our test car. But complaining about the price of the California would be as vulgar as building a 50-acre theme park in Abu Dhabi. It's a Ferrari, it's supposed to be special. And the California really is.

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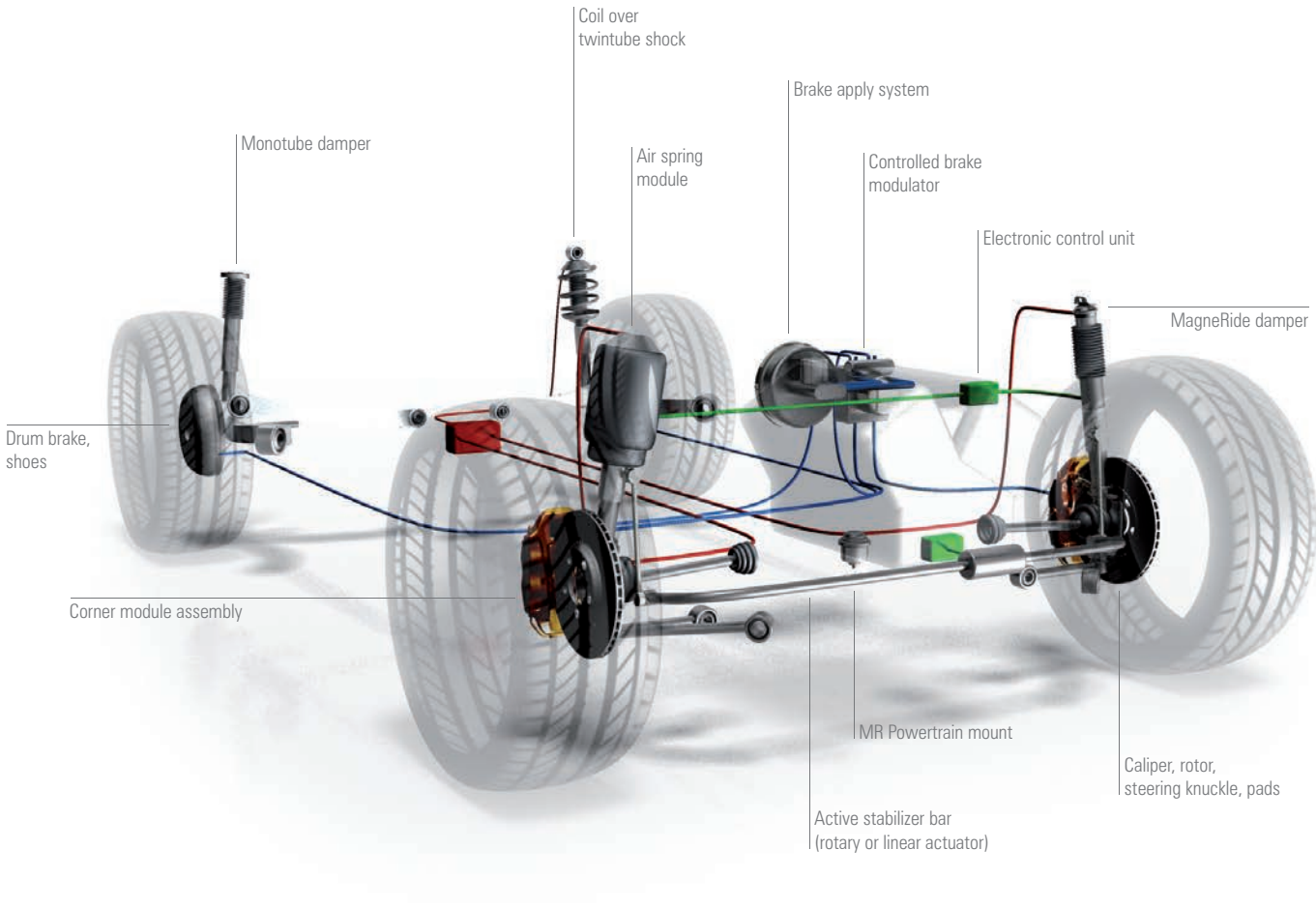

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