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MX-5

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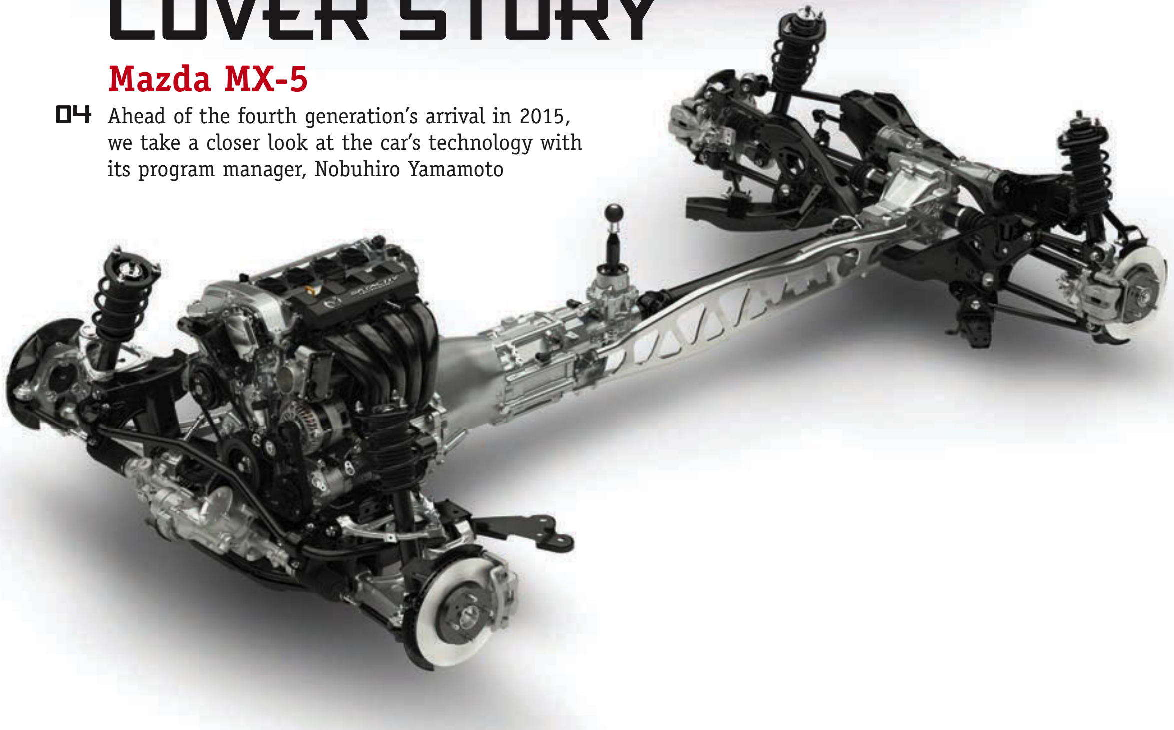
COVER STORY

Mazda MX-5



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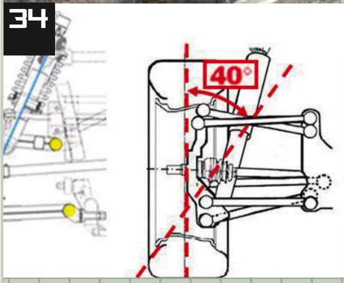

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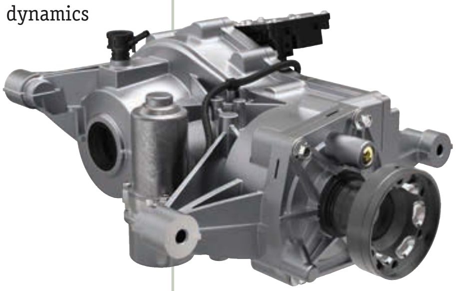

Vehicle Dynamics International
Abinger House, Church Street,
Dorking, Surrey, RH4 1DF, UK
editorial tel: +44 (0)1306 743744
editorial fax: +44 (0)1306 875824
sales tel: +44 (0)1306 741200
sales fax: +44 (0)1306 743755
email: vehicledynamics@ukipme.com

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EDITORIAL
Editor **John O'Brien**
Editor-in-chief **Adam Gavine**
Production editor **Alex Bradley**
Chief sub editor **Andrew Pickering**
Deputy chief sub editor **Nick Shepherd**
Proofreaders
Aubrey Jacobs-Tyson, Christine Velarde
Contributors this issue
John Challen, Matt Davis, Graham Heeps, John Heider, John Miles, Keith Read

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

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

CEO
Tony Robinson
Managing director
Graham Johnson
Editorial director
Anthony James

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A NOTE FROM THE EDITOR

I must be getting old: I've been questioning the point of fast cars, or more specifically ultra high-powered modern sports saloons and hot hatches. Does anyone really need a car with over 300bhp for a daily commute? I've also been pondering what passes as acceptable in terms of ride and comfort these days. What has brought on this contemplation? The purchase of a second-hand, cheap runaround, while my Subaru Impreza is off the road.

The car in question is a Volkswagen Golf MK3 GTi, 2.0 8v. That's right, the bloated GTi of the early 1990s that is still loathed in Volkswagen circles for single-handedly undoing the sterling reputation of the second-generation GTi 16v.

And yet, my new acquisition has surprised me. Reviews at the time noted the extra weight the third-generation carried over its predecessor, and the detrimental effect it had on handling – most prominently the tendency to understeer. The reality is that the ride offered by the 17-year-old Golf is perfect for me, as the road surfaces in the area around the *VDi* office and my home outclass the diversity of most proving grounds.

The softly sprung GTi has handled these roads with ease, and though the 2.0 8v engine produced only 115bhp when new, it feels the correct amount for the car; full acceleration moments result in achieving speeds well within the legal highway limit. The body-roll of the car lends a softer approach to cornering, and the modestly profiled 15in tires give just enough slip to let you know the limit is near.

All in all, the Golf has made my commute much more enjoyable and pleasant than it ever was in my two-door rally refugee. This is also true of some modern cars I've driven recently, albeit those pitched at the opposite end of the spectrum from my Impreza. New sedans, sports cars and even SUVs all now have as standard specification that would once have comprised much of the options list.

Large diameter wheels, sports suspension and the vast array of electronic stability aids that are commonplace in all classes of car combine to make a 300bhp hatchback perfectly acceptable – or even the norm – nowadays.

The Golf has proved to be the perfect antidote to this madness. The cosseting ride and almost underpowered nature of the car are perfect for the daily commute. The revised driving style that the car enforces returns over 40mpg – and with technology that was developed over two decades ago.

In all market segments, we are generating ever-larger, heavier cars, with increasing engine sizes to compensate. And so I began thinking… Is it all necessary? Bigger is not always better.

John O'Brien

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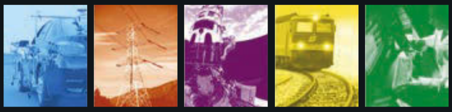

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THE FOURTH-GENERATION MAZDA MX-5 IS A RETURN TO THE MODEL'S ROOTS: LIGHTER WEIGHT AND SIMPLER, TO DELIVER FANTASTIC DYNAMIC PERFORMANCE

NOBUHIRO YAMAMOTO, PROGRAM MANAGER FOR THE MX-5

For 25 years, Mazda's MX-5 has been a benchmark sports car. As with most models, however, each generation of the vehicle has grown in dimensions, weight and ultimately power to compensate for the extra bulk. The fourth generation aims to reverse this trend, returning to a curb weight comparable with the original. Given that the original MX-5 was a modern interpretation of the Lotus Elan, the new generation does ring true of the Lotus philosophy of achieving performance through simplicity and light weight.

"It's also worth noting that this model has the shortest length of all the generations of MX-5, including the original," explains Nobuhiro Yamamoto, program manager for the MX-5. "It is 100mm shorter than the previous-generation MX-5, and 50mm shorter than the original. But because of the way it has been styled, it doesn't give that impression – the silhouette hides this well."

Complementing this svelte silhouette, and at the core of Mazda's claims for the car, is that over 100kg has been shaved from the curb weight. Yamamoto states that this cannot be attributed to one area of the car in particular; it is simply the result of making tiny savings from every area and aspect of the two-seater.

"When we started planning the fourth-generation model, we had to revisit the origins of the MX-5, and we asked what is it that started the [public's] love for the car?" explains Yamamoto. "We decided that returning to the car's origins was key to the concept, as we couldn't continue this trend of making longer and heavier vehicles; that was not the way we wanted to go with this car. The MX-5 isn't simply just another form of mobility to get you from A to B."

Early planning meetings for the car began back in 2007. However, the MX-5's development program was temporarily put on hiatus in 2009 during the global recession. "This had two detrimental effects

THE FOURTH-GENERATION MX-5'S REDUCED WEIGHT HAS ENABLED THE DOWNSIZING OF SEVERAL MAJOR COMPONENTS

"We couldn't develop cars anything like we had done previously. As a result, every division and team within the company that would be involved with the car's development came together"
Nobuhiro Yamamoto, MX-5 program manager

on the project," explains Yamamoto. "Firstly, we had to delay the program. And secondly, the company as a whole became very strict in controlling the development of products from a monetary point of view. We couldn't develop cars anything like we had done previously. As a result, every division and team within the company that would be involved with the car's development came together, and we created a clear vision on what the car should be, and ensured we all stuck to that vision."

The basis of the development program is the same Japanese expression that has echoed through each iteration of the MX5: 'Jinba ittai' (horse and rider as one). Sticking to these principles was of strong importance to Yamamoto. "We wanted to innovate in order to preserve," he explains. "We didn't want to create an evolution, we wanted to add an element of innovation to the MX-5."

As a result, the fourth-generation car retains similar underpinnings to the third-generation model, but makes use of lightweight materials to reduce overall mass. At the front of the car is a conventional double-wishbone configuration, with both control arms formed from aluminum, along with aluminum anti-roll bar linkages, brake calipers and steering rack housing.

"This generation uses an aluminum steering knuckle," says Yamamoto. "In the third generation they were steel, so we have saved weight further in this area."

By reducing the unsprung mass of the car, the team was able to downsize the brakes, which Yamamoto says enabled a reduction in engine size and overall weight. Yamamoto states that there are examples of this domino effect all over the car, and one of the external tell-tale signs of the weight reduction is a return to four-stub wheel hubs, from the previous generation's 5x114.3pcd units.

These lightweight elements are complemented by a traditional steel anti-roll bar, steel subframe and steel steering control arm ends. While the car's styling may appear relatively unchanged from the previous generation, there has been a strong trend of downsizing throughout the design.

MAIN IMAGE: **THE STYLIZED BODY OF THE LATEST-GENERATION MX-5 CONCEALS ITS SMALLER DIMENSIONS** INSET: **THE ORIGINAL MX-5 FROM 1989 WAS A HUGE SALES SUCCES FOR MAZDA. SEE PAGE 72 FOR A FOND LOOK BACK AT THE ORIGINAL MX-5**

THE MX-5'S UNDERPINNINGS ARE AN EXAMPLE OF EVOLUTION NOT REVOLUTION. THE PRINCIPLES THAT FORM THE MK4 HAVE BEEN IN PLACE FOR SEVERAL GENERATIONS

For example, the rack and pinion steering system has been carried over from the previous generation, only now mated to an electronic assistance system. Yamamoto is keen to highlight that the new system is mounted low within the car, on the rack itself as opposed to the column, as in other Mazda models. While ensuring lower CO_2 emissions and weight, electronic power steering systems are often criticized in the mainstream automotive media for their lack of feel. With the MX-5 famed for its precise steering feel, how did the development team of the new model combat this potentially ruinous trait?

"We achieved a constant feel through the wheel by simply keeping the assistance function to the bare minimum – this was a very important achievement for us," explains Yamamoto. "Another point that is absolutely vital for steering feel is the angle of the column, from the rack to the wheel. We wanted to keep it as straight as possible as this is key to driver enjoyment."

The development of the MX-5's rear end is a similar story to the front end. The multilink setup has been carried over from the previous generation, but revisions to the suspension geometry have seen the suspension top mounts lowered significantly over the third generation, while carrying a more aggressive spring angle. Yamamoto is keen to highlight that this design also benefits the car from an aesthetic perspective, allowing for a highly stylized swooping rear panel, which hugs the rear wheel.

MAZDA'S SKYACTIV TECHNOLOGY UNDERPINS THE NEW MX-5 AND IS ATTRIBUTED TO THE SUBSTANTIAL WEIGHT SAVINGS SEEN IN THIS GENERATION CAR

Yamamoto believes that one of the most crucial elements of the MX-5's rear suspension is the rear cross-member. Heavily revised from the previous-generation unit, the updated cross-member now passes below the rear differential, as opposed to above it.

"The significance of this design, once again, goes back to the basic engineering principles outlined at the start of the project," concludes Yamamoto. "As the input is coming across the structure from the driveshafts, if we can have a cross-member with as straight a line geometry as possible that can still hold the load, you can keep the actual structure to a minimum, while retaining the rigidity of something more complex. If you have to go over, as before, you introduce curvature to the structure, which means it will not take the same loading without adding reinforcement and ultimately weight."

When it came to benchmarking the car against rivals, Mazda is of the opinion that there is nothing that directly competes with the MX-5 in the same category, and instead conducted a series of comparison tests with previous generation models. "That's not to say we've ignored other vehicles," explains Yamamoto. "We didn't benchmark them, but we drove the Porsche Cayman S, the Nissan GT-R and the BMW Z4. We drove them to see what they feel like – it's not necessarily a benchmarking activity, but we are aware of what's out there."

Curiously, a big rival to the MX-5 will come from within – Mazda is developing and building a closely related roadster for Fiat. It was initially announced that the car would be badged as an Alfa Romeo, but it may now appear as an Abarth. Yamamoto explains that responsibility for the testing and development of the new model lies solely with Mazda.

"I'd like to make it clear that it is not a joint development," he concludes. "While it's true that the car will have Fiat engines, the development is solely down to us. Of course, having this relationship, they [Fiat] have requests they like to make. But the final responsibility is with Mazda as the OEM, so it's being done to Mazda standards."

VDI SAYS

The fourth-generation MX-5 marks a return to simplicity and a focus on driving for fun. With the Mk1 MX-5 a firm favorite among driving enthusiasts, we are definitely looking forward to driving the Mk4.


Better Handling
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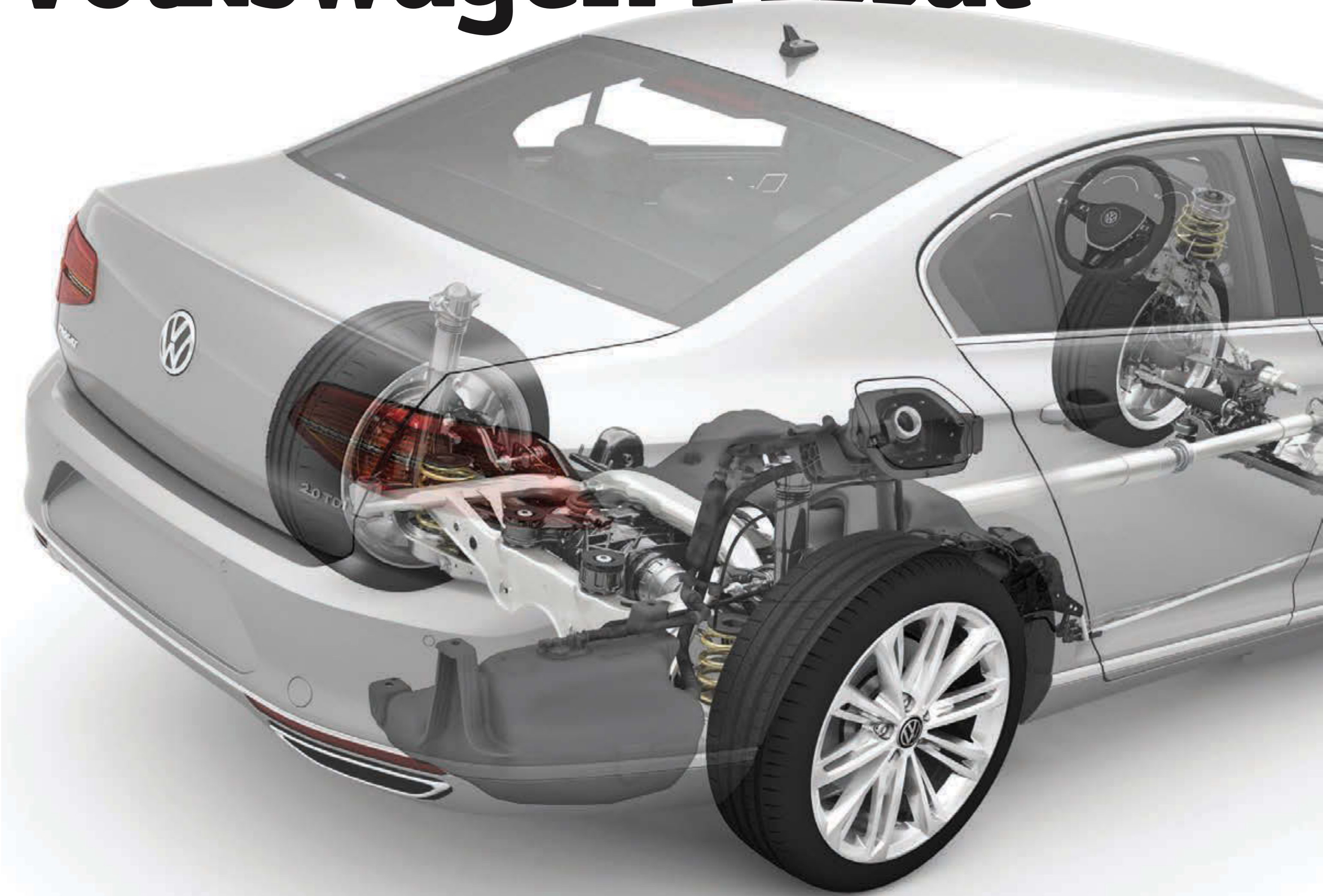
Volkswagen Passat



ONE OF THE MOST IMPORTANT MODELS FOR VOLKSWAGEN, THE EIGHTH-GEN PASSAT IS ALL-NEW AND BASED ON VOLKSWAGEN'S MQB-B MODULAR TOOLKIT

The all-new Volkswagen Passat is an important model for the company. In 2013, on average, a Passat was sold every 29 seconds, making it one of the Volkswagen Group's best sellers. And in total, some 22 million units have been produced since the model's arrival in 1973.

This eighth-generation model is based on Volkswagen's Modularer Querbaukasten (MQB), or modular transversal toolkit, and the first derivative of the MQB-B platform. This brings with it several revisions over the MQB-A platform, which has spawned several Golf-sized models already.

The Passat's front suspension takes elements from the smaller MQB-A platform as well as introducing elements from the previous Passat's platform. "One significant improvement that you can see in the front suspension is the inclusion of an aluminum cross-member, which we have used on previous generations," explains Jürgen Pützschler – technical development, chassis tuning at Volkswagen. "Comparing MQB-A to MQB-B, though, it is a significant improvement as we were in a position to reduce weight, but significantly improve the stiffness of the cross-member."

Volkswagen states that the sub-frame is centrally positioned on the front axle, and has been designed to deliver maximum transverse rigidity, handling loads from the engine mounts, steering and front suspension.

High-tensile steel has been used throughout the Passat's construction, resulting in the car weighing some 90kg less than the previous generation. The application of the material within the chassis contributed 4.6kg toward the overall reduction.

The front suspension is based on a conventional MacPherson strut, and makes use of high-tensile steel in the transverse links. "It is a traditionally designed strut, but the shock absorber has a new tune, while the spring rates have been improved too," states Pützschler. "This is to better compensate side loads, and so the inclination of the spring within the MacPherson strut has been revised too. We had side-load compensation on the previous models

FAR LEFT: **THE FRONT AXLE, WITH A THICKER ANTI-ROLL BAR AND A REVISED SPRING INCLINATION ANGLE**

LEFT: **THE MODULAR REAR AXLE IS NEW FOR DEVELOPMENT FOR THE PASSAT**

ABOVE: **THE CUTAWAY SHOWS THE DISTRIBUTION OF METALS WITH VARIOUS GRADES AND STRENGTHS WITHIN THE PASSAT'S SHELL**

MAIN IMAGE: **THE PASSAT'S MODULAR UNDERPINNINGS MEAN THAT THE TECHNOLOGY USED WILL FILTER THROUGH TO SEVERAL OTHER MODELS WITHIN VOLKSWAGEN**

as well, but the inclination angle of the spring within the MacPherson axis should be optimized as soon as you significantly change the front weight and weight ranges of the car."

The anti-roll bars have also been revised for this eighth-generation model. Now fully tubular in shape, the unit is significantly lighter, while the rubber bearings are vulcanized directly onto the painted bar. Volkswagen states that the benefits of this are two-fold, in that it delivers optimal acoustic properties, while also optimizing the responsiveness of the bar itself.

The car's rear suspension is based on a modular performance rear axle. "In comparison with the seventh-generation Passat, this is a completely new development," explains Pützschler. "It would be better to compare it to the MQB-A, as the concept arrived on that platform. In comparison with that platform, however, we have reprofiled the elastokinematics and kinematics as we are carrying higher loads with the Passat. We also have an isolated rear-subframe, which the MQB-A doesn't have, and we developed that purely to address the delivery of improved comfort."

The rear axle is a four-link unit, which separates the car's longitudinal and transverse rigidities. Volkswagen states that the Passat's low longitudinal rigidity has been preserved by the trailing link's soft axle control, and that it has improved the transverse rigidity of the modular performance axle to improve steering feel.

Volkswagen's revisions to achieve this include revised steering link bearings and design changes to the anti-roll bar linkages. "It was previously attached to the rear knuckle, and now it attaches to the spring link," explains Pützschler. "This gave us significant opportunities in respect of the car's packaging; the interior of the vehicle is much larger, despite the car being much smaller externally. But that was one of the things we had to do in order to give those opportunities to the packaging team."

The Passat's electronic power-steering is available in two variations: linear and progressive. The optional progressive steering takes 2.1 turns of the wheel from lock to lock, while the standard, linear option takes 2.75 turns.

"The linear system is a new system that we developed for MQB-B, which we will now carry backward onto the MQB-A platform as well," explains Pützschler. "In addition to that, the tuning of the progressive system is also new to the Passat. One of the highlights, in my opinion, of the new systems is that we were able to create a steering feel significantly closer to what we would all like to have – hydraulic steering.

"What a steering system needs to deliver is essentially intuitiveness and precision," concludes Pützschler. "To achieve that, you need to deliver a perfect balance between steering wheel torque, yaw gain and vehicle roll. This movement between steering wheel torque and steering wheel angle, as well as yaw gain and vehicle roll, is something very important to achieving intuitive vehicle behavior. In the past, that is something that has been difficult to achieve when creating a natural steering feel, and I think we've made a very significant step toward that with the latest-generation system."

***VDI* SAYS**

The new Passat is a very well-rounded car, offering superb performance in a very appealing package, although the range-topping biturbo's grunt is stifled somewhat by the additional weight of the 4Motion system

Discovery Sport

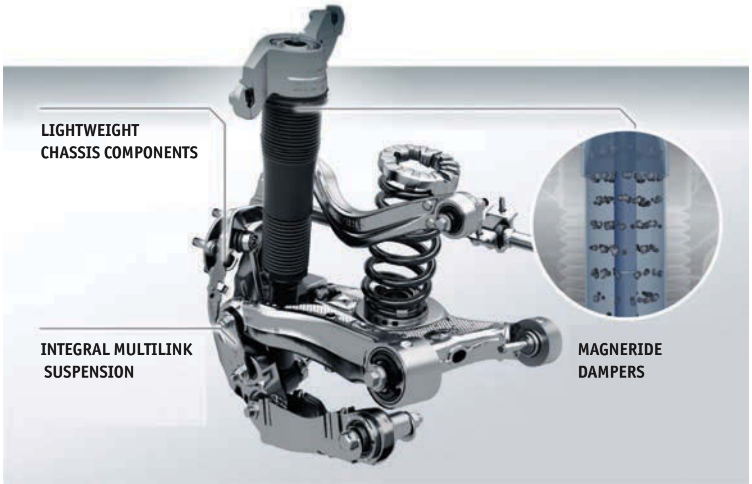
LAND ROVER'S LATEST MODEL, THE DISCOVERY SPORT, MAKES USE OF AN ALL-NEW MULTILINK REAR AXLE TO ALLOW 5+2 SEATING IN A COMPACT BODYSHELL

Land Rover's new model offensive continues with the introduction of the Discovery Sport. This new addition to the Discovery family has a new multilink rear axle and several other new technologies that will eventually find their way into other Land Rover products.

While the Discovery Sport is based on the Range Rover Evoque architecture, the integral-link rear suspension is much more compact than the Evoque's, allowing a 5+2 seating arrangement to be specified.

However, the benefits of the complex multilink rear axle extend much further than offering customers a third row of seats. The setup enables wheel travel and axle articulation up to 340mm, a figure Land Rover claims is over 60mm more than competing models.

The lower control arm and rear suspension knuckle are produced from thin-walled hollow aluminum castings, which help reduce the vehicle's unsprung mass, while increasing strength within the components. The rear suspension is mounted on an isolated steel subframe, again to aid weight loss and improve dynamics.



The Discovery Sport's front suspension comprises conventional coil springs, with steel front lower control arms and aluminum suspension knuckles. The vehicle also has hydraulic rebound stops on the dampers, which Land Rover states result in "excellent refinement". Land Rover also states that the hydraulic rebound also helps to minimize noise entering the cabin, after the suspension has been compressed over particularly large potholes.

All Discovery Sport derivatives are available in four-wheel-drive configuration. The full-time four-wheel-drive system continuously varies the torque split from front to rear, and makes use of the latest Haldex center coupling, which is around 4kg lighter than the previous unit used by Land Rover.

The car also features torque vectoring by braking (TVB), which operates on the vented 325mm front, and 300mm rear disc brakes. The front brakes are of a new design, with a stiffer caliper and newly developed pad compound, which is claimed by Land Rover engineers to enhance retardation and to reduce the amount of brake dust produced.

Development of the car took around 3.5 years, with the majority of the work being supplemented by digital development. "Over the course of about a year and a half, we used our virtual capability at Gaydon intensively, most notably the CAVE," explains Paul Cleaver, vehicle program director for the Discovery Sport. "This was vital for the complexities of the Discovery Sport's rear end.

"Because we made a major upgrade to the Evoque's architecture with the new rear suspension, the durability and crash work was redone, so we weren't able to save time on physical testing," he continues.

That test work also applied to CAE testing for areas such as NVH (modal analysis) and stiffness analysis, although some time was saved because many of the CAE models could be derived from the Evoque.

THE DISCOVERY SPORT'S MULTILINK REAR SUSPENSION (BELOW AND RIGHT) **IS A COMPACT UNIT THAT OFFERS UP TO 340MM OF AXLE ARTICULATION** (TOP)

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On the job

JOHN MILES RECALLS THE TIMES OF GENIUS – AND SOMETIMES TROUBLED GENIUS – AT LOTUS, WITH LEADERSHIP CHANGES, ENGINEERING CHALLENGES, ACTIVE SUSPENSION AND THE ELUSIVE NEW ESPRIT

It was 1983. Colin Chapman had died the year before, weighed down by the DeLorean affair, the banned twin-chassis Lotus 88 and declining car production. His commitment to fund a full Active Suspension research vehicle lived on, as did the embryo Vehicle Engineering section – a group of three engineers, led by Roger Becker, that was soon to quintuple in size and had chassis development at its forefront.

The Lotus Sunbeam (winner of the 1981 World Rally Championship for Makes), suspension revisions on the Supra and a driver training contract with Toyota had been completed. A big tuning job on a V6 GM Cavalier was next and – heresy – we were looking at front-wheel drive for the new Elan! I was winter testing FWD versus RWD Corollas (FWD outperformed on every test) when I found out that GM had bought Lotus from the caretaker shareholders: Toyota, Amex and BCA (British Car Auctions). Despite initial fears, GM's ownership turned out to be a golden period for the company, especially with the Active Suspension project.

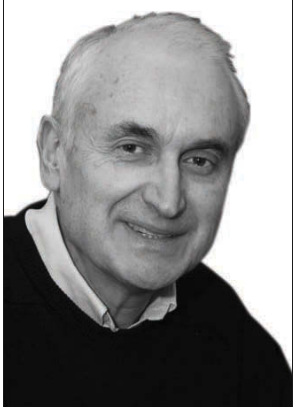
Active Suspension was conceived for F1 at a time when skirted ground-effect downforce was so powerful that the cars had to be bone-breakingly stiff to keep them off the ground. With the active system, the car could be relatively soft, with the actuators, which synthesized spring behavior, extending to programmed positions to compensate for downforce. Soft meant grip, and helped Ayrton Senna win two GPs in the Lotus Renault Turbo 97T.

With engineer Mike Kimberley continuing as CEO and Peter Wright as a technical guru switching between Team Lotus and Lotus Cars, there was a real engineering feel about the place. GM, Toyota, Saab and Volvo were buying Active Suspension research vehicles as fast as Lotus could make them.

Things were humming along, but as brilliant as Active Suspension was as a race car system and as a research tool for road cars, it was super-sensitive to set up, and difficult to isolate from extraneous disturbances. There was even a moment when it looked like the system was going to take over in the luxury vehicle sector. Unfortunately, engineers soon found out that the pump noise, actuator friction and other problems associated with 2,500psi hydraulics, together with those of driving actuators through rubber mountings with immense authority, were unsolvable – not to mention the system's cost and potential instability.

When I first rejoined Lotus in 1984, the passive group also had a wake-up call because the idea of kinematic or compliance toe-out front axle-steer being necessary for straight-line stability was unheard of by me, or anybody else at Lotus, at the time. In fact, Chapman's race car bump-steer setup was firmly in place and concentrated on eliminating any steer effects. Yet at least 10 years earlier, GM, VW and others knew all about the importance of compliance and kinematic steer-effects, especially for cars with laterally weak twist-beam rear axles. As tires were becoming more responsive, understanding and controlling small steer effects was becoming critical.

> "As brilliant as Active Suspension was as a race car system and as a research tool for road cars, it was super-sensitive to set up"



Rumblings about a replacement Esprit were always present, a car that by now had been transformed from the original due to three things. Chapman's original rear concept of having the driveshaft as the top-link required extra-stiff gearbox mounts to handle the cornering loads; awful NVH and indifferent handling resulted. Chapman's complaints about the humming roughness in the cabin could be easily solved with the inclusion of a top suspension link, a plunging driveshaft and soft gearbox mounts, yet he forbade chief chassis designer Ken Heap from making these changes. Chapman went on vacation and instructed Heap to have fixed the car by the time he returned, saying, "and I don't care how you do it". On his return two weeks later, Chapman drove a transformed car and asked what had been done. "You told us to fix the NVH, or else, so we fitted a top link," replied Heap.

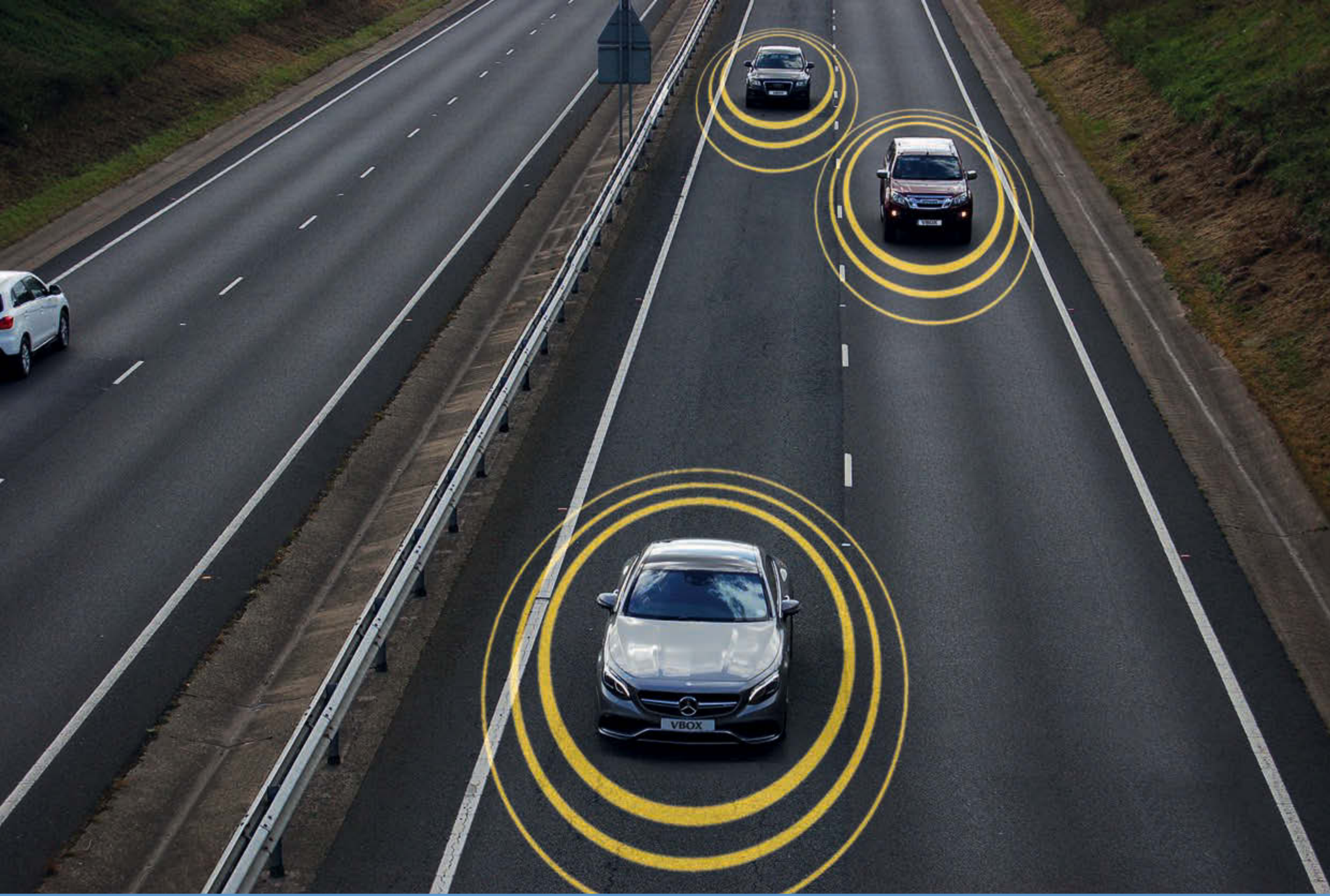
Vehicle engineering was booming, and the passive chassis group was expanding fast, with contract work for GM, Rolls-Royce and even Ford. The FWD Elan was now in production, and the place was humming, especially in the engineering team, which was working on innovations such as noise synthesis, an F1 engine for Toyota, lots of powertrain work and a relaunch of Team Lotus.

All was about to change. By 1993, the US economy was not going so well and GM surprised us all by selling to Bugatti, led by the charismatic Romano Artioli. Kimberley had departed and over the next three years the Elise and the S2 Elan were brought out.

By 1996, a virtually bankrupt Lotus had been through three managing directors, but then Tan Sri Yahaya Ahmad of Proton came riding to the rescue, installing ex-Shell Oil executive Chris Knight as CEO.

One must hand it to Proton (and now DRB-HICOM) for continuing to invest in Lotus and its facilities. A bright spot during the 15-year period of Proton/DRB-HICOM ownership was the return of Kimberley in 2006. Thanks mainly to Kimberley, and Roger Becker's strong long-term links with Toyota, the Evora was built. Incredibly, the whole program took a mere 27 months from start to finish and cost just £36m – Lotus at its absolute best.

Kimberley departed in 2008, once the Evora was in production, ushering in a new period under the leadership of Danny Behar, and a return to F1. In spite of some difficult times in its 62-year history, the Lotus brand survives, but again, what of a new Esprit?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Self-drive dynamics

FOR JOHN HEIDER, AUTONOMOUS CARS DO NOT MEAN THE END FOR DYNAMICS ENGINEERS

I evaluated an autonomous vehicle last night on the way home from a local restaurant. Last week, my family and I evaluated an autonomous vehicle from our house to the airport. "How is this possible?" you ask. Well, it depends on your interpretation of 'autonomous'. In our vehicle dynamics-centric world, if we are not the ones behind the wheel, does it really matter if the vehicle is controlled by an array of sensors and actuators or a live human being chauffeuring us from one location to another?

Semantics aside, the technical challenges of creating, developing and integrating the required technologies to allow autonomous operation of a vehicle are daunting. Having said that, the number of OEMs, large and small corporations, government agencies and universities involved in the development of software, hardware and regulations to make some form of self-driving vehicles possible is truly impressive. Rarely in the history of modern vehicles have so many resources been focused on a single goal.

As with any step-change in technology, the implementation will occur in many phases over an extended period. We are already well into the initial phase of autonomous vehicles. Some production vehicles offer lane-keeping assist, self-parking, active cruise control, active braking, 360° vision cameras and stop-and-go traffic assist – all becoming mature, well tested and widely adopted technologies. The only questions left to answer are, how fast and how far do we go?

So where does this leave the vehicle dynamics engineers of today who are working on such 'mundane' things as ride, handling, steering and braking performance? Do we throw up our hands and walk away in disgust? Hardly.

Fast-forwarding to a world where large numbers of autonomous vehicles are traveling well-mapped routes, ride comfort becomes the vehicle dynamics attribute of prime importance. By definition, a customer who is willing to let a vehicle control itself would prefer to be doing things other than driving.

Although an autonomous vehicle allows occupants to divorce themselves from the acts of steering, braking and maintaining the speed of the vehicle, it does not divorce them from road-induced disturbances. Just as turbulence on an airplane causes everyone to close their reading material, close their eyes and wait for it to end, the inability to easily type, text or write while traveling over uneven surfaces will be off-putting. (Then again, perhaps those forms of communication will also be antiquated in this world.)

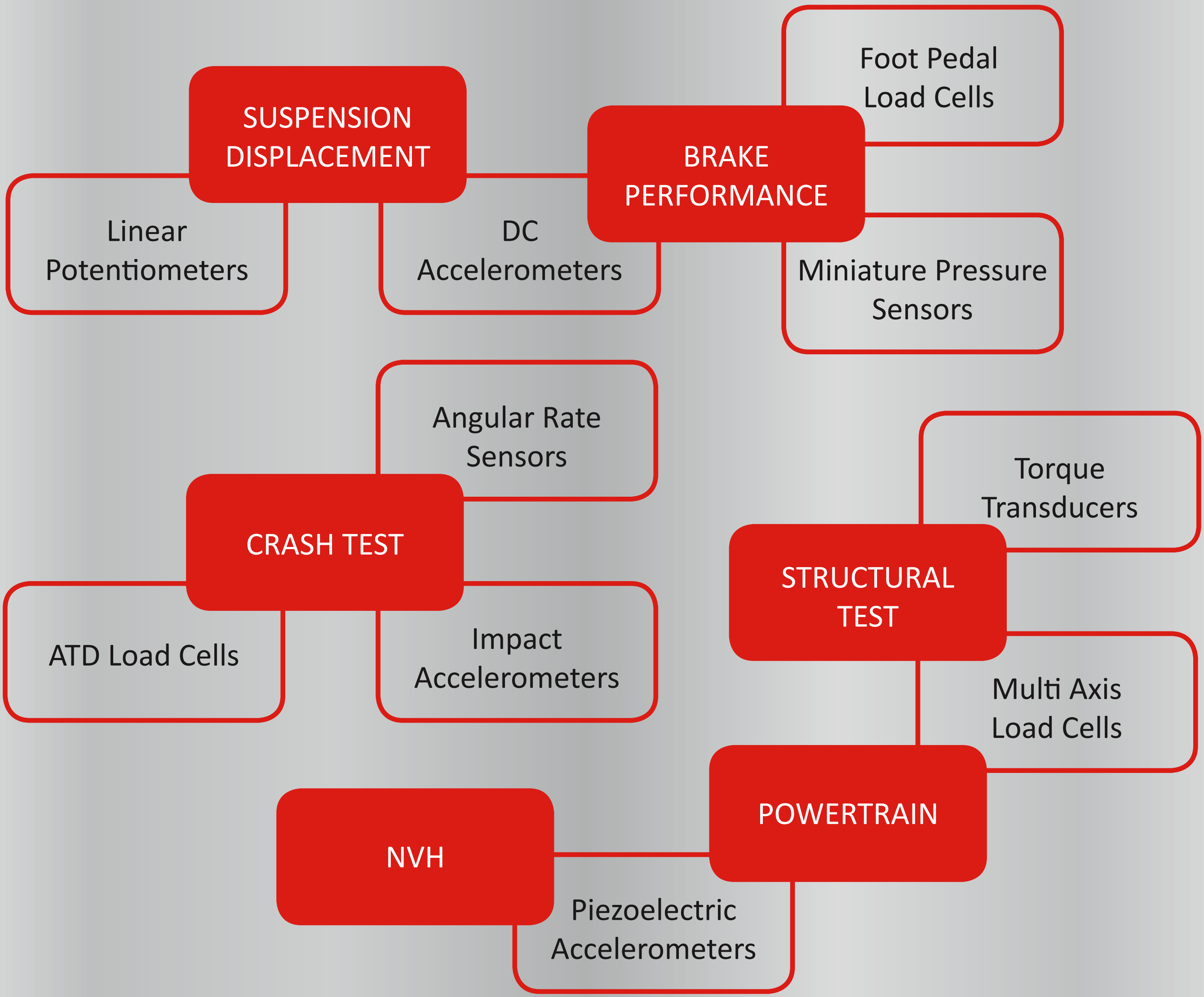
> "If a vehicle cannot be accelerated, braked or steered smoothly by an average driver, then something is amiss"

Impact harshness, shake, jiggle, head toss or pitch imbalances will invariably upset the riders focused on their work rather than on the road. Vehicle dynamics engineers currently tasked with reaching appropriate compromises between ride and steering/handling performance will be judged solely on achieving acceptable ride comfort.

This is not to say that steering, handling and braking performance can be overlooked. One of the tenets of vehicle dynamics development is that a passenger vehicle should always flatter the driver. If a vehicle cannot be accelerated, braked or steered smoothly by an average driver, then something is amiss. Steering systems with excessive torque or angle deadbands when on-center; non-linear responses throughout the driving range and poor directional stability, can all serve to make a good driver appear average and an average driver appear poor. The same concept applies to braking systems. Current development work on brake controls and active safety systems suggest that the 'driver' referenced above can be man or machine. Simply put, the human body is an extremely good control system; if it is struggling to easily accomplish the task of driving a vehicle smoothly, then an extremely sophisticated electronic control system will face the same challenges.

As with today's vehicles, one of the most intriguing and debated attributes of autonomous vehicles will be emergency handling performance. The debates will happen in the public and private domain as well as courts of law. The more things change, the more things stay the same for a vehicle dynamics engineer.

John Heider is from Cayman Dynamics LLC, a company that provides vehicle dynamics expertise to the transportation industry

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Detecting critical situations

SÉBASTIEN VARRIER FROM LCIS AND **DAMIEN KOENIG** AND **JOHN J MARTINEZ** FROM GIPSA-LAB PRESENT THEIR FINDINGS ON NEW METHODS FOR DETECTING CRITICAL SITUATIONS IN VEHICLE LATERAL DYNAMICS

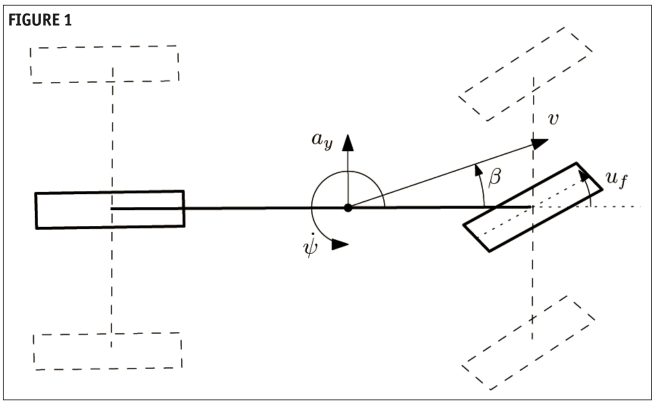
The automotive market is constantly striving to achieve greater comfort and security for vehicles. As a consequence, the automotive industry has focused on the development of smart systems in recent years, in order to improve those aspects. However, in 2009, the World Health Organization was still attributing 2.2% of fatalities to vehicle collisions and loss of vehicle stability.

In recent years, it has been noted that active and passive technologies, such as ABS, ESP, ACC, etc, are mostly developed from kinematic (and/or dynamic) models of the vehicle in order to allow for simplicity in implementation. Although those components fit most new vehicles, their lack of robustness and the absence of dynamical/adaptive components has been criticized.

Concerning lateral dynamics, ESP is the most commonly used active safety equipment for maintaining the stability of a vehicle in the event of a loss of control. An ESP system comprises sensors (steering wheel angle, longitudinal vehicle speed, accelerations and rotational speeds in the center of gravity) and braking actuators.[8,9] The objective of ESP is to detect any under- or over-steering and to then activate the brakes in order to correct the trajectory of the vehicle. For example, if the radius of curvature of the vehicle is larger than desired (over steering), the ESP will lock the inner wheels in order to correct the trajectory. The ESP is based on the bicycle model with two degrees of freedom presented in Figure 1. The system has a cascade structure whereby it first detects the loss of stability through algebraic computations, and then takes corrective braking action using mechanical components.

FIGURE 1 (BELOW): **THE DYNAMICAL VEHICLE MODEL, SIMPLIFIED AS A TWO-WHEELED MODEL**

FIGURE 1



Current approaches to detecting a loss of vehicle stability are too restrictive, and not robust enough. We propose a new, more robust approach, which is dependent on vehicle speed. The vehicle is modeled as a bicycle model, whereby the lateral friction forces are considered as non-linear. Several situations are considered: normal driving, critical situations, or if the vehicle has lost stability. 'Normal driving' is characterized by a linear lateral friction force, and when in the critical or skidding zone, the force is highly non-linear.

As a consequence, the difference between the linear tire model and the real data from the vehicle enables a classification of the situation: normal, critical (or skidding). This difference is at the heart of the approach. The detection of a critical situation is finally rewritten as a fault detection problem, where the fault is the difference between the nominal model and the real system. The fault-detection approach has been chosen as a robust approach, which is oriented toward implementation.[6]

Several fault-detection approaches exist. The model-based approaches are the most commonly handled ones. The approaches based on analytical redundancy[7,10] are interesting due to their low implementation complexity (load). There also exist some statistical or geometrical approaches[11,12,13] and some based on observation. It has recently been observed that the emergence of model-based approaches, based on an optimization process, minimizes the effect of uncertainties while maximizing the effect of the faults on the residual, such as $H\infty$ approaches solved by linear matrix inequalities (LMIs).[14,15] Those methods are mostly designed for LTI systems; however, some methods have been recently designed for parameter varying systems (LPV).[6,16,17]

The proposed approach[6] is well adapted for this problem as it allows a smart synthesis adapted to the implementation target.

MODELING OF THE VEHICLE

An example vehicle is presented in Figure 1. The control input of the vehicle is the steering wheel angle υ_f. According to the sensors inboard of the vehicle, lateral acceleration α_y can be sensed thanks to an accelerometer, or the yaw rate ψ with a gyrometer. The vehicle longitudinal speed v makes an angle β – called the side-slip angle – with respect to the longitudinal vehicle axis.

FIGURE 2

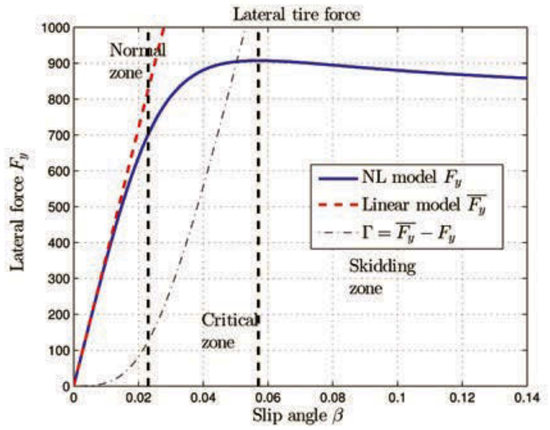


FIGURE 3

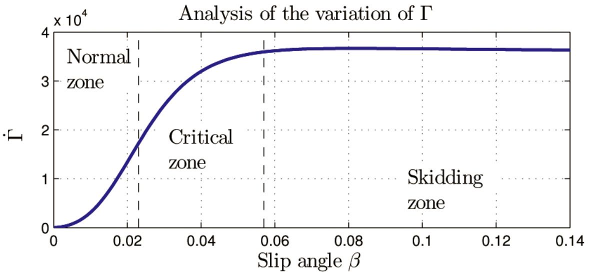


FIGURE 2 (ABOVE LEFT): **LATERAL TIRE FORCE**
FIGURE 3 (ABOVE): **ANALYSIS OF THE VARIATION OF Γ**

The dynamic model enables the four-wheel vehicle model to be simplified into a two-wheel model, called the bicycle model. This model yields the following dynamical equations of its dynamics

$$\begin{aligned} mv(\dot{\beta}+\dot{\psi}) &= F_{yf}+F_{yr} \\ I_z\ddot{\psi} &= l_fF_{yf}-l_rF_{yr} \end{aligned} \qquad \textbf{1}$$

where m represents the total vehicle mass, I_z its inertia around the vertical axis, l_f and l_r respectively represent the distance from the center of gravity to the front axle and respectively to the rear one.

Forces F_{yf} and F_{yr} represent the front and rear lateral tire forces of the vehicle. Their modeling is proposed in the following section.

MODELING OF TIRE FORCES

In the literature, there exist several models of lateral tire forces.[2,3,4]

Among those models, one of the most used is the Pacejka model, where the lateral force F_y is given in function of the side-slip angle β_i of the wheel (where i stands for front (i=f) or rear (i=r)) by:

$$F_{yi} = D\sin\left[C\arctan\left(B\beta_i - E(B\beta_i - \arctan(B\beta_i))\right)\right] \qquad \textbf{1A}$$

This model is based on experimental data that allows for refining the parameters B, C, D and E. The graphical representation of this model is presented in Figure 2.

According to this non-linear tire model, three working regions can be observed: the normal zone, which is the region where the tire friction is correct, and tire force can be assumed to be linear in this region; the critical zone, where friction is limited; and the skidding zone, where the tire skids on the road.

As a consequence, in normal operation, the lateral forces F_{yf} and F_{yr} can be a given function of the slip angles β_f and β_r by the relations:

$$\overline{F_{yf}} = c_f\beta_f \qquad \textbf{2A}$$

$$\overline{F_{yr}} = c_r\beta_r \qquad \textbf{2B}$$

with:

$$\beta_f = u_f - \beta - \frac{l_f\dot{\psi}}{v} \qquad \textbf{3A}$$

$$\beta_r = -\beta + \frac{l_r\dot{\psi}}{v} \qquad \textbf{3B}$$

In order to take into account the non-linear component of the tires, the real forces $F_{yi,i=f,r}$ are modeled as the combination of its nominal (linear) component plus a non-linear one $\Gamma_{i,i=f,r}(\beta)$ as:

$$F_{yf} = \overline{F_{yf}} + \Gamma_f(\beta) \qquad \textbf{4A}$$

$$F_{yr} = \overline{F_{yr}} + \Gamma_r(\beta) \qquad \textbf{4B}$$

By analyzing the function $\Gamma(\beta)$, it can be shown that its derivative is always positive in its definition (Figure 3). Thanks to this conclusion, it can be shown that the linear model always over-evaluates the real lateral force. Moreover, in the linear/normal region, the difference between both models is small, while in the critical region the difference is far more significant.

COMPLETE VEHICLE MODELING

From the dynamic model given in Equation 1, and the forces modeled in Equations 3 and 4, the vehicle dynamics can be given by:

$$\begin{aligned} mv(\dot{\beta}+\dot{\psi}) &= c_fu_f-(c_r+c_f)\beta \\ &\quad +\tfrac{(c_rl_r-c_fl_f)}{v}\dot{\psi}+\Gamma_f+\Gamma_r \\ I_z\ddot{\psi} &= l_fc_fu_f-\tfrac{l_f{}^2c_f-l_r{}^2c_r}{v}\dot{\psi} \\ &\quad (l_rc_r+l_fc_f)\beta+l_f\Gamma_f-l_r\Gamma_r \end{aligned} \qquad \textbf{5}$$

and can be written under the following state space form:

$$\begin{aligned} \begin{bmatrix}\dot{\beta}\\ \ddot{\psi}\end{bmatrix} &= \begin{bmatrix} -\frac{c_r+c_f}{mv} & \frac{c_rl_r-c_fl_f}{mv^2}-1 \\ \frac{l_rc_r-l_fc_f}{I_z} & -\frac{l_f{}^2c_f+l_r{}^2c_r}{I_zv}\end{bmatrix}\begin{bmatrix}\beta\\ \dot{\psi}\end{bmatrix} \\ &\quad +\begin{bmatrix}\frac{c_f}{mv}\\ \frac{l_fc_f}{I_z}\end{bmatrix}u_f+\begin{bmatrix}\frac{1}{mv} & \frac{1}{mv}\\ \frac{l_f}{I_z} & -\frac{l_r}{I_z}\end{bmatrix}\begin{bmatrix}\Gamma_f\\ \Gamma_r\end{bmatrix} \end{aligned} \qquad \textbf{6}$$

In equation 6, the classical bicycle model can be recognized, plus the additional deviations Γ_i between the linear and non-linear models.

The problem of detection of critical situations can now be rewritten as a fault detection problem, where $\Gamma_{i,i=f,r}$ stand for the fault that have to be detected.

According to the under/oversteering characteristic of the vehicle, the detection of a critical situation can be confined to the detection of one component of Γ_i. In fact, for an under- or oversteering vehicle, the front axle reaches the critical zone first. As a consequence, only the component that skids the most easily can be studied. However, a global synthesis that detects both components allows for consideration of all kinds of vehicles and is more general.

It has to be pointed out that the model in Equation 6 is speed-dependent. This system is discretized according to the rectangular discretization[5], and is rewritten under the discretized linear parameter varying system form:

$$\begin{aligned} \begin{bmatrix}\beta\\ \dot{\psi}\end{bmatrix}_{k+1} &= \left(\begin{bmatrix}1 & -T_d\\ T_d\frac{l_rc_r-l_fc_f}{I_z} & 1\end{bmatrix}\right. \\ &\quad +\frac{1}{v_k}\begin{bmatrix}-T_d\frac{c_r+c_f}{m} & 0\\ 0 & -T_d\frac{l_f{}^2c_f+l_r{}^2c_r}{I_z}\end{bmatrix} \\ &\quad \left.+\frac{1}{v_k{}^2}\begin{bmatrix}0 & T_d\frac{c_rl_r-c_fl_f}{m}\\ 0 & 0\end{bmatrix}\right)\begin{bmatrix}\beta\\ \dot{\psi}\end{bmatrix}_k \\ +\left(\begin{bmatrix}0\\ T_d\frac{l_fc_f}{I_z}\end{bmatrix}\right. &+ \left.\frac{1}{v_k}\begin{bmatrix}T_d\frac{c_f}{m}\\ 0\end{bmatrix}\right)u_f+\begin{bmatrix}\frac{T_d}{mv} & \frac{T_d}{mv}\\ T_d\frac{l_f}{I_z} & -T_d\frac{l_r}{I_z}\end{bmatrix}\begin{bmatrix}\Gamma_f\\ \Gamma_r\end{bmatrix} \end{aligned} \qquad \textbf{7}$$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where $\rho_{1k} \triangleq \frac{1}{v_k}$, $\rho_{2k} \triangleq \frac{1}{v_k^2}$ are the scheduling parameters and T_d is the chosen sampling period.

The data y_k is obtained thanks to a gyrometer in the vehicle that senses the yaw rate in the center of gravity

$$y_k \triangleq \dot{\psi}_k = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \beta \\ \dot{\psi} \end{bmatrix}_k$$

FAULT DETECTION

The fault detection methodology is inspired by Equation 6. The proposed approach rests on the parity in space methodology as initiated in Equation 7. The objective is to rewrite the LPV system as a combination of LTI uncertain systems, where the uncertainty depends of the scheduling parameters. The most interesting part of this approach is that it relies on the fact that the system is very easy in terms of synthesis, and is adaptable to the implementation target.

The objective of the proposed method is to override the complexity induced by the scheduling parameters in the system. The LPV system is rewritten as the switched commutation of a sub-LTI uncertain system according to the scheduling parameters.

The uncertainty concerns the region of variation between the different subsystems. For instance, as illustrated in Figure 4, the systems depends on the scheduling parameter ρ and is rewritten as the combination of four sub-LTI uncertain systems, depending on the value of the scheduling parameter ρ. Each subsystem can have its own region of validity.

The LPV system Σ_{LPV} can be rewritten:

$$\Sigma_{LPV} = \prod_{i=1}^{4} \mu_i(\rho) \Sigma_{i_{LTI\ \text{uncertain}}} \qquad \textbf{8}$$

where

$$\mu_i(\rho) = \begin{cases} 1 & \text{si } \rho \in \begin{bmatrix} \underline{\rho}_i & \overline{\rho}_i \end{bmatrix} \\ 0 & \text{sinon} \end{cases} \qquad \textbf{9}$$

Each sub-LTI system is considered to be uncertain where the uncertainty represents the variation of the scheduling parameter inside its region. According to each subsystem, a robust residual face to the variation of the parameters can be synthesized. The final residual is finally given as the switched commutation of the different sub-residuals.

Fault detection for uncertain systems

In this study, the affine uncertain form is considered as presented in Equation 10:

$$\Sigma_i : \begin{cases} x(k+1) = & \overline{A}x(k) + Bu(k) + B_d d(k) + B_f f(k) \\ y(k) = & \overline{C}x(k) + Du(k) + D_d d(k) + D_f f(k) \end{cases} \qquad \textbf{10}$$

where the over-barred matrices X stand for uncertain matrices, $x \in R^n$ represents the state of the system, $y \in R^m$ the outputs, $\in R^l$ the inputs, $d \in R^d$ the unknown inputs and $f \in R^f$ the faults.

The uncertain matrices are considered under the affine form:

$$\overline{X} = X_0 + \sum_{i=1}^{N} \widetilde{X}_i \delta_i = X_0 + \underbrace{\begin{bmatrix} \widetilde{X}_1 & \widetilde{X}_2 & \cdots & \widetilde{X}_N \end{bmatrix}}_{\widetilde{X}} \underbrace{\begin{bmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_N \end{bmatrix}}$$

where X_0 represents the nominal component of the matrix, X_i are known matrices and δi some unknown scalars.

The system in Equation 10 can be rewritten under the form:

$$\begin{aligned} x(k+1) &= A_0 x(k) + \widetilde{A\delta} x(k) + Bu(k) \\ &\quad + B_d d(k) + B_f f(k) \\ y(k) &= C_0 x(k) + \widetilde{C\delta} x(k) + Du(k) \\ &\quad + D_d d(k) + D_f f(k) \end{aligned} \qquad \textbf{11}$$

By applying the parity space methodology, the outputs y are expressed along an horizon s, obtaining the following expression:

$$\begin{aligned} Y_s(k) - H_{us}U_s(k) = H_{os}x(k) + \sum_i \left(\varsigma(i) \widetilde{H}_{os,i} \right) x(k) \\ + \sum_i \left(\varsigma(i) \widetilde{H}_{us,i} \right) U_s(k) + H_{ds}U_{ds}(k) \\ + \sum_i \left(\varsigma(i) \widetilde{H}_{ds,i} \right) U_s(k) + H_{fs}F_s(k) \end{aligned} \qquad \textbf{12}$$

where ζ is built from δ, the power of its elements and multiple inner products:

$$\varsigma = \begin{bmatrix} \delta_1 & \cdots & \delta_N & \delta_1\delta_2 & \cdots & \delta_1{}^p & \cdots & \delta_N{}^{s+1} \end{bmatrix}$$

Matrices and vectors of Equation 12 are in the form:

$$Y_s = \begin{bmatrix} y(k) \\ y(k+1) \\ \vdots \\ y(k+s) \end{bmatrix}, U_s = \begin{bmatrix} u(k) \\ u(k+1) \\ \vdots \\ u(k+s) \end{bmatrix}, H_{os} = \begin{bmatrix} C_0 \\ C_0A_0 \\ \vdots \\ C_0A_0^{s-1} \end{bmatrix},$$

$$H_{us} = \begin{bmatrix} D & 0 & \cdots & \cdots & 0 \\ C_0B & D & 0 & \cdots & 0 \\ C_0A_0B & C_0B & D & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & 0 \\ C_0A_0^{s-1}B & C_0A_0^{s-2}B & \cdots & C_0B & D \end{bmatrix},$$

$$H_{fs} = \text{diag}(D_f, \cdots, D_f).$$

The trivial parity space approach would consist of synthesizing a parity matrix W in order to be orthogonal to H_{os}, and also to the matrices linked to uncertainties W^T $[H_{os}\ \widetilde{H}_{os}\ \widetilde{H}_{us}\ H_{ds}\ \widetilde{H}_{ds}]$ = 0. However, the existence of such a matrix is never guaranteed, due to its large size.

FIGURE 4

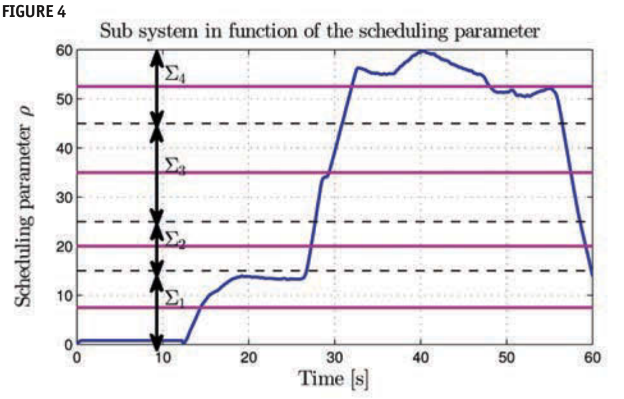

FIGURE 4: **THE PRINCIPLE OF THE APPROACH TO FAULT DETECTION**

The objective would lie in finding an optimum sub-space in the sense of the optimization problem presented in Equation 14. This work results in a 'non-optimal' matrix W, which solves the problem.

SYNTHESIS OF THE PARITY MATRIX

The objective is of synthesizing a matrix W in order to get a residual r build from known data of the system as:

$$r(k) = W^T (Y_s(k) - H_{us}U_s(k))$$

The residual r has to be the most sensitive to the faults f, while being non-receptive to the uncertainties δ_i, nor to the unknown inputs d. This problem can be rewritten as an optimization problem (see Equation 14), where the constraint $W^T H_{os}$ is preserved in order to guarantee an optimal result with respect to the nominal system:

$$\text{find } W \text{ such that} : \begin{cases} W^T H_{os} = 0 \\ \max\limits_W \left\| W^T H_{fs} \right\|^2 \\ \min\limits_W \left\| W^T \widetilde{H}_{os} \right\|^2 \\ \min\limits_W \left\| W^T \widetilde{H}_{us} \right\|^2 \\ \min\limits_W \left\| W^T H_{ds} \right\|^2 \end{cases} \qquad \textbf{14}$$

which can be rewritten under the following optimization form:

$$\mathcal{P}_1 : \begin{cases} W^T H_{os} = 0 \\ \min\limits_W \dfrac{\left\| W^T G \right\|^2}{\left\| W^T H_{fs} \right\|^2} \end{cases} \qquad \textbf{15}$$

$$\text{where } G = \begin{bmatrix} \widetilde{H}_{os} & \widetilde{H}_{us} & H_{ds} & \widetilde{H}_{ds} \end{bmatrix}$$

It has to be pointed out that this optimization problem is constrained, so it is difficult to solve.

However, with some algebraic manipulation, it can be turned

FIGURE 5

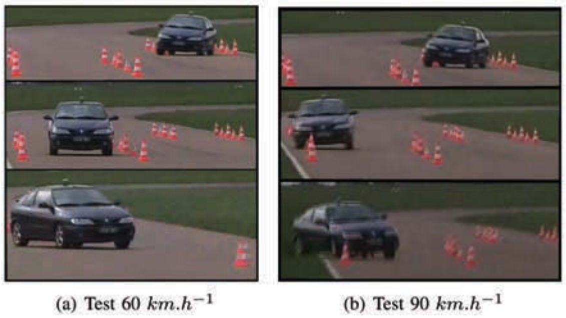

FIGURE 6

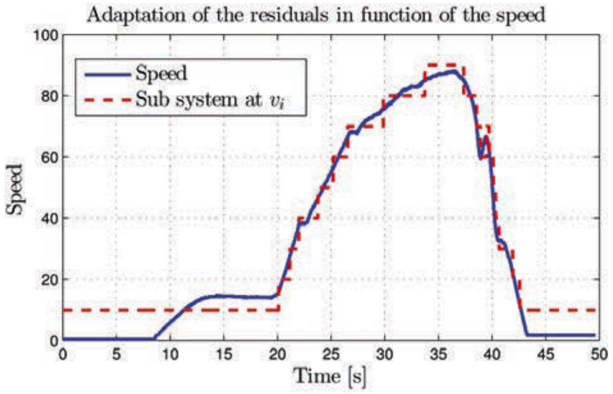

FIGURE 5 (ABOVE): **EXPERIMENTAL VALIDATIONS AT 60 AND 90KM/H**

FIGURE 6 (ABOVE RIGHT): **ADAPTATION IN THE FUNCTION OF THE SPEED**

into the form of an unconstrained optimization problem. To reach this objective, the constrained H_{os} is structured as:

$$H_{os} = \begin{bmatrix} H_{os1} \\ H_{os2} \end{bmatrix} \qquad \textbf{16}$$

where the matrix H_{os1} is regular, and so invertible.

Finally, in order to guarantee the constraint, the matrix W is constrained by P. The previous constrained optimization problem (Equation 15) in the variable W is rewritten as an unconstrained optimization problem in the variable W_2:

$$\begin{aligned} \mathcal{P}_1 : \quad & \min_{W_2} \frac{\|{W_2}^T PG\|^2}{\|{W_2}^T PH_{fs}\|^2} \\ & = \min_{W_2} \frac{{W_2}^T \Gamma_1 W_2}{{W_2}^T \Gamma_2 W_2} \end{aligned} \qquad \textbf{19}$$

where $\Gamma1$ and $\Gamma2$ are symmetric matrices defined by: $\Gamma1 = PGG^T P^T$ and $\Gamma2 = PH_{fs}H_{fs}^{T\,PT}$.

By rewriting W as in Equation 18, the solution of Equation 19 satisfies the constrained $W^T H_{os}$ by its construction. So, the constrained part is no longer a problem.

Theorem 1 finally allows us this optimization problem to be solved:

Theorem 1: Given an optimization problem in the form:

$$\gamma^* = \min_X \frac{X^T AX}{X^T BX} \qquad \textbf{20}$$

where A and B are symmetric matrices, the minimum γ^* according to the criterion in Equation 20 is reached by X^* such that:

$$X^* = \vartheta_{\lambda_q(A,B)} \qquad \textbf{21}$$

where $\lambda_q(A,B)$ represents the smallest generalized eigen-value of the pair (A,B), and $\vartheta\lambda_{q\ (A,B)}$ its associated generalized eigenvector. The minimum γ^* is given by $\gamma^* = \lambda_q\,(A,B)$.

The proof is given in Equation 6.

Thanks to this theorem, the optimization problem $P1$ (Equation 19) is solved by:

$$\mathcal{P}_1 : {W_2}^T = \vartheta_{\lambda_q(\Gamma_1,\Gamma_2)} \qquad \textbf{22}$$

So the parity matrix W is reconstructed thanks to Equation 18.

EXPERIMENTAL VALIDATIONS

In order to highlight the previous exposed theory, some tests have been done in the framework of the ANR/INOVE project. The MIPS laboratory, a partner in the project, owns an equipped vehicle as illustrated in Figure 5.

In order to validate the proposed approach, one scenario consists of the Moose test for different longitudinal speeds: 30,60 then 90km/h^{-1}. The Moose test is an obstacle avoidance maneuver, which enables the road-holding of a vehicle to be evaluated.

The path begins with a left-hand bend, then there is a chicane maneuver. The Moose test was passed, except at 90km/h^{-1}, when the vehicle left the path and spun.

For the detection of critical situations, the model in Equation 7 was used in order to synthesize the residual. The model is composed of two scheduling parameters, depending on the vehicle speed:

$$\rho_1 = \tfrac{1}{v} \text{ et } \rho_2 = \tfrac{1}{v^2} = {\rho_1}^2$$

According to vehicle speed, different residuals have been synthesized. The residuals are generated for nominal speeds $v0_i$ every 10km/h^{-1}, with variations δ_v of ±5km/h^{-1}. The scheduling parameter $p1$ is given by:

$$\rho_{1k} = \frac{1}{v_k} = \frac{1}{v_0 + \delta_v}$$

By making a first-order approximation, it can be approximated by:

$$\rho_{1k} \simeq \frac{1}{v_0} - \frac{\delta_v}{{v_0}^2} \qquad \textbf{23}$$

From the discrete time LPV system presented in Equation 7, nine subsystems have been considered in order to synthesize residuals using the approximation given in Equation 23:

Σ_{LTI}	v_0	Σ_{LTI}	v_0
Σ_{LTI1}	$10km.h^{-1}$	Σ_{LTI6}	$60km.h^{-1}$
Σ_{LTI2}	$20km.h^{-1}$	Σ_{LTI7}	$70km.h^{-1}$
Σ_{LTI3}	$30km.h^{-1}$	Σ_{LTI8}	$80km.h^{-1}$
Σ_{LTI4}	$40km.h^{-1}$	Σ_{LTI9}	$90km.h^{-1}$
Σ_{LTI5}	$50km.h^{-1}$		

In this practical application, the informatics resources mean a large computation load can be considered. Many subsystems have been considered and a low variation of the scheduling parameters was also considered. However, according to the implementation target, the number of subsystems can be adapted in order to reduce the computation load by increasing the variation δ_v.

The composition of the different residuals is done by realizing a switched combination of the different residuals as a function of the speed (Figure 6).

The residual is implemented on the vehicle, for the three different tests. The results are presented in Figure 7.

It can be observed that when the vehicle is in a normal situation


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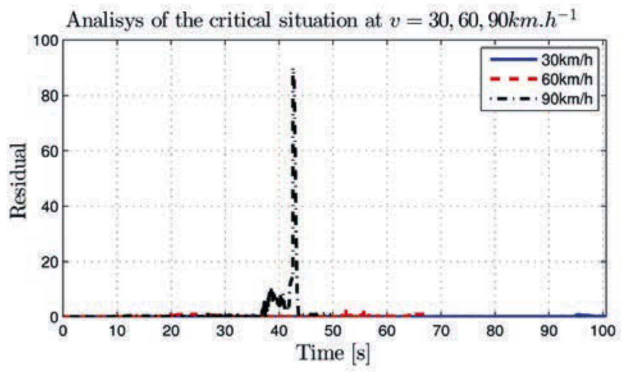
be certain.

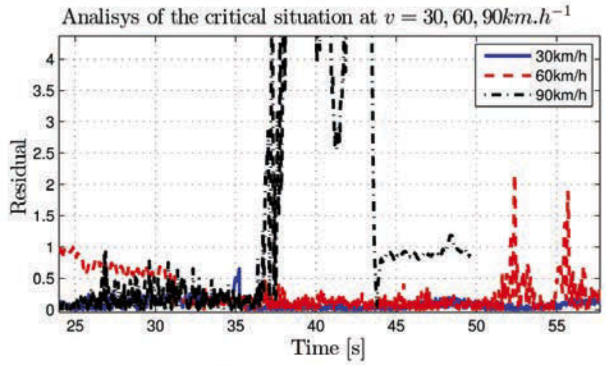
FIGURE 7A (RIGHT): **THE RESIDUAL FOR THE THREE SPEEDS OF 30, 60 AND 90KM/H**
FIGURE 7B (BELOW RIGHT): **A CLOSER LOOK AT THE RESIDUALS**

FIGURE 7A



(a) Residual for the 3 speeds

FIGURE 7B



(b) Zoom on the residuals

(30km/h^{-1} and 60km/h^{-1}), the residual remains small (Figure 7). However, when the situation becomes critical (at 90km/h^{-1}), the residual becomes far larger due to the loss of stability of the vehicle. It can be observed that at time $t = 37s$, the residual deviates significantly, showing that the vehicle has lost stability.

CONCLUSION

In this paper, an approach for the detection of critical situations has been presented. The idea in this application rests on the modeling of the vehicle via the bicycle model, where the tire model is considered as linear. In practical situations, the real force is no more linear in critical situations. The difference between theory and practice can be considered as a fault that has to be detected.

A robust fault-detection approach oriented for implementation has been presented in order to detect the critical situation, and the results have been applied to a real vehicle. An obstacle avoidance maneuver has been experienced at three different working speeds: $v = 30$, 60 and 90km/h^{-1}. At the first two speeds, the moose test was passed, while at 90km/h^{-1}, the vehicle lost stability and spun. The synthesized residual was kept small during the first two experiments, but became very high when the vehicle lost its stability. A threshold can be added to the residual in order to anticipate the loss of stability and correct its trajectory.

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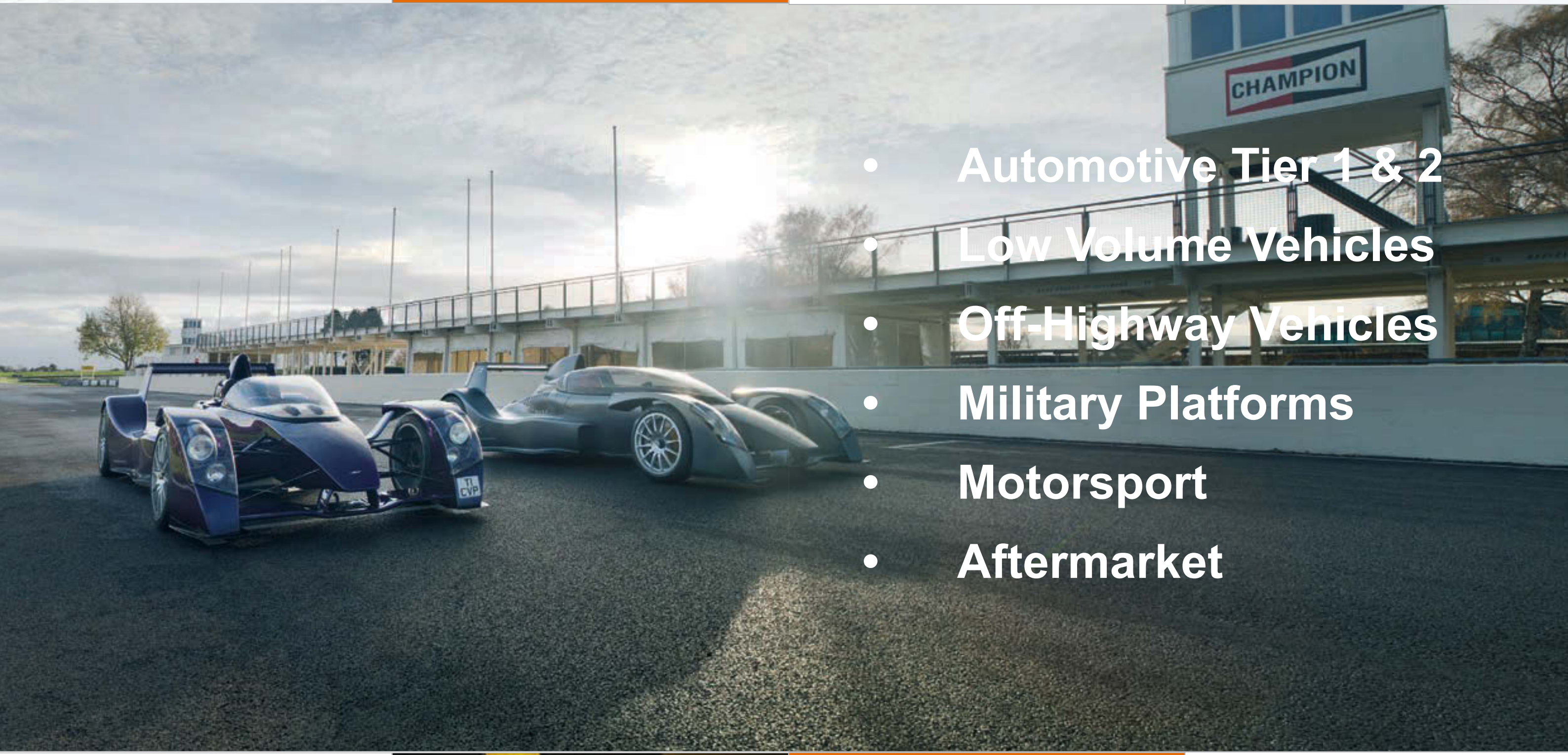

CHAMPION

Interaction models

AN ANALYSIS OF THE RESULTS PROVIDED BY A GRIP AND THERMODYNAMICS-SENSITIVE TIRE/ROAD INTERACTION FORCE CHARACTERIZATION PROCEDURE. BY **FLAVIO FARRONI**, UNIVERSITY OF NAPLES

FIGURE 1: **MODEL INTEGRATION SOLUTIONS**

FIGURE 2: **G-G DIAGRAM REALIZED BOTH WITH EXPERIMENTAL DATA AND WITH RESULTS OF A SIMULATION PERFORMED WITH STARTING MF-TIRE PARAMETERS SET**

FIGURE 3: **DETAIL OF THE FRONT** (LEFT) **AND REAR** (RIGHT) **TIRE SLIP ANGLES, BOTH FROM EXPERIMENTAL DATA AND FROM OUTPUTS OF A SIMULATION PERFORMED WITH STARTING MF-TIRE PARAMETERS SET**

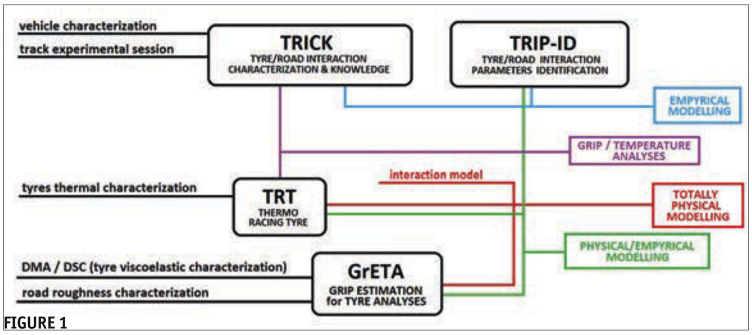


FIGURE 1

The automotive sector is looking for the optimal solution in modeling and understanding tire behavior in experimental and simulation environments. [1,2,3] The studies and tools described here represent a new approach in tire characterization and vehicle simulation procedures, leading to the complete reproduction of the dynamic response of a tire and of its frictional and thermodynamic behavior simply by means of specific track sessions and a few laboratory measurements. This represents a bridge between a robust and widespread approach, like Pacejka's, and purely physical modeling, that satisfies predictive requests and the need for deeper knowledge about complex phenomena.

The tools

The final product is composed of the following four tools, which can cooperate to form a multitude of solutions.

TRICK (Tyre/Road Interaction Characterization & Knowledge)[4] is basically composed of a vehicle model able to process experimental signals acquired from the vehicle's CANbus and from additional instrumentation (DATRON[5]) to estimate sideslip angle, providing a sort of virtual telemetry, based on the acquired signals' time history and containing force and slip estimations useful to provide tire interaction characteristics.

Complete and detailed studies of tires in a wide range of working conditions are commonly carried out by means of complex, bulky and expensive test benches.[6] The proposed procedure means the vehicle can be employed as a moving lab, easily applying experimental and processing techniques.

TRIP-ID (Tyre/Road Interaction Parameters Identification) provides an innovative procedure to identify the Pacejka coefficients, starting from the experimental tests carried out to measure global vehicle data during outdoor track sessions. The procedure collects and processes the data provided by TRICK, eliminating the outlier points, discriminating between the various tire wear and thermal phenomena, and taking into account the combined slip condition and the effects of vertical load and camber angle on the overall grip.

TRT (Thermo Racing Tyre)[7] is an analytical-physical thermal tire model developed with the aim of predicting temperature with a high degree of accuracy and able to simulate the high-frequency thermal dynamics characterizing high-performance systems. The model can estimate the temperature distribution of even the deepest tire layers, usually not easily measurable online, to predict the effects that fast temperature variations induce in the behavior of viscoelastic materials, and to take into account the dissipative phenomena related to tire deformations.

GrETA (Grip Estimation for Tyre Analyses)[8] is a tire/road friction physical model, developed to respond to the needs of race teams and tire

FIGURE 2

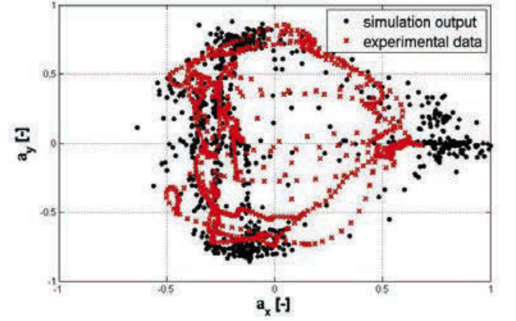
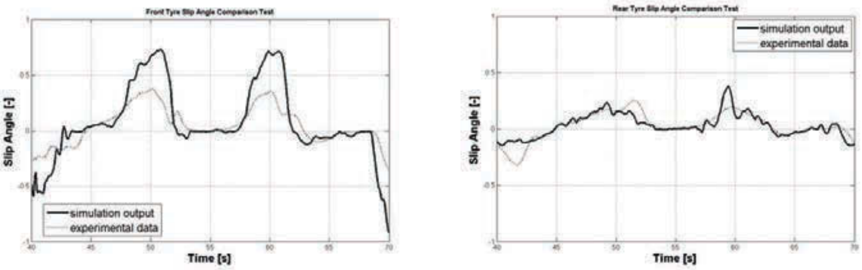


FIGURE 3



manufacturers, able to provide an effective calculation of the power dissipated by road asperities indented in the tire tread, taking into account the phenomena involved with adhesive friction, expressed by means of an original formulation whose parameters are identified thanks to dedicated experimental tests.

These tools are able to describe and analyze aspects of phenomena concerned with tire/road interaction, but their cooperation can constitute an even more powerful instrument to extend the comprehension of such a complex theme.

A general overview of the developed models and procedures is shown in Figure 1, in which it is possible to observe the connections that link the models, providing different solutions for employment.

TRICK and TRIP-ID

TRICK and TRIP-ID were developed with the initial aim of increasing the confidence of car makers in adopting the Magic Formula in virtual drive modeling and vehicle dynamics models employed for predictive performance analyses. One of the main advantages of the tool is the ability to validate Pacejka coefficients provided by tire makers, or even do without their contribution, identifying coefficients after a proper vehicle characterization and a specific track session.

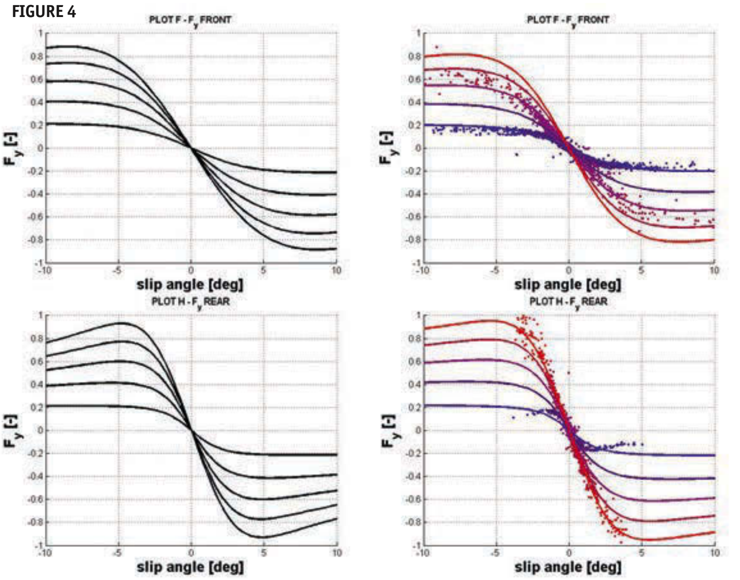
The weak points of the initial MF-Tyre parameter set identified by tire companies via bench procedures, and highlighted by data analysis, are as follows: First, there is too much grip in the longitudinal and lateral interaction, due to the differences between real roads and the belts employed for testing.

Next, there is a lower likelihood than in reality for the driver to be able to stabilize the vehicle after the limit of adhesion has been crossed.

FIGURE 4: **PLOT F** (LEFT)**: STARTING SET, FRONT TIRE, PURE LATERAL INTERACTION. PLOT F** (RIGHT)**: IDENTIFIED FINAL SET, FRONT TIRE, PURE LATERAL INTERACTION. PLOT H** (LEFT)**: STARTING SET, REAR TIRE, PURE LATERAL INTERACTION. PLOT H** (RIGHT)**: IDENTIFIED FINAL SET, REAR TIRE, PURE LATERAL INTERACTION**

FIGURE 5: (RIGHT) **G-G DIAGRAM REALIZED BOTH WITH EXPERIMENTAL DATA AND WITH RESULTS OF A SIMULATION PERFORMED WITH THE FINAL IDENTIFIED MF-TIRE PARAMETER SET.** (LEFT) **FIGURE 2 FOR COMPARISON**

FIGURE 4



Finally, there is an absence of grip and stiffness variations due to thermal effects.

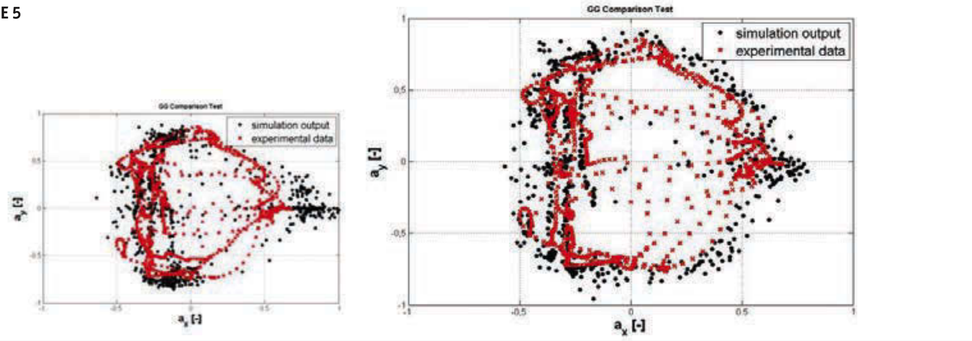
In Figure 2, a G-G diagram, a classic and simple instrument employed to evaluate global vehicle performance,[9] is plotted (in nondimensional form, as are all the following ones, for reasons of industrial confidentiality), comparing on a reference track lap the measured vehicle accelerations with accelerations exported as output from a commercial, highly validated vehicle simulation model employed in a virtual driving simulation environment that has been adopted for the specific MF-Tyre parameter set provided by the tire maker.

High grip levels reached by bench-tested tires are often due to the testing countersurface being abrasive paper (or rough material characterized by low macro-roughness), that is able to maximize the contact patch's effective area, providing an interface better than a real road.

The employment of abrasive paper and severe testing cycles causes, in addition to grip overestimation (and consequent to it), a continuous and massive heat generation at the contact interface, which increases tire temperature. As is well known, one of the main effects of temperature on tires is stiffness variation[2] (increasing temperature causes decreasing stiffness), particularly evident in the front tires, which in high-performance applications are typically narrower and less thermally inert than the rears. Figure 3 focuses on these considerations, highlighting the unsatisfactory results obtained with respect to front slip angles employing the starting tires' parameter set; the imbalances caused by poor estimation of slip angles act on the whole vehicle's tendency to understeer or oversteer.[10]

The identification of the optimal parameter set by means of the TRIP-ID procedure also enables us to solve the simulated vehicle driveability problems linked to the shape of the tires' starting set. The mentioned lower-than-reality likelihood of the driver returning the vehicle to a stable condition after the limit of adhesion has been crossed is due to two factors: an excessively peaky trend of lateral interaction curves and a too-sharp decrease of cornering force in a combined interaction at increasing values of slip ratio. The improvement that the characterized tires have represented with respect to the cited effects can be observed in Figure 4, which compares the starting set's pure lateral interaction curves (on the left, in black) with

FIGURE 5



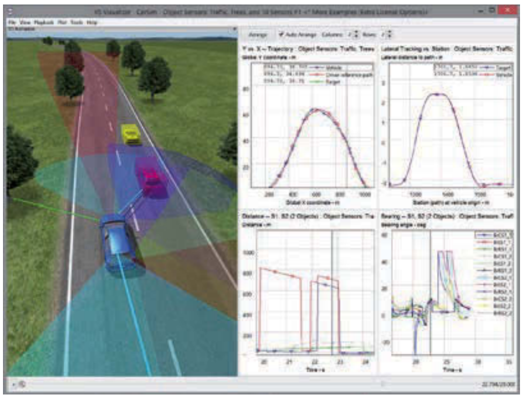


FIGURE 6

those of the optimal identified set (on the right, colored).

It can be seen that data collected during an experimental session and processed by the TRICK tool is able to provide information useful in modifying the starting set, obtaining an identified set that results in good agreement with the drivers' requests and with the objective data acquired by equipping the vehicle with measurement instruments. Figure 5 shows the results of the simulations performed with the identified tire set, comparing them with the ones relative to the starting set, shown on the left.

TRICK and TRT

TRICK and TRT can be successfully employed together, providing an instrument able to provide tire thermal analyses, useful to identify the range of temperature in which grip performances are maximized and enabling the optimal tires and vehicle setup to be defined.

The test procedures adopted to characterize the tires, obtaining data useful to initialize the models properly, can be schematically divided into two main subcategories – destructive and non-destructive.

To the first belongs meridian plane section analysis. This kind of test consists of the observation and measurement of the thickness of the layers constituting the meridian section. In Figure 6, it is possible to distinguish the tread layer, characterized by an evident and deep pattern, the bulk layer, in which steel cord plies are clearly observable, and the innerliner, which is very thin and impermeable.

The second component of the destructive subcategory is thermal conductivity and specific heat measurements. Tire layers need to be characterized from a thermodynamic point of view, focusing in particular on conductivity and specific heat measurements. A standard test procedure is carried out employing a Stabilite 2017 argon-krypton laser (Figure 7a) pointed at the whole tire or on specimens of each layer and emitting a beam of given power. Knowing the specimen thickness and measuring temperature of the two surfaces by means of two thermographic cameras (a Flir Phoenix, Figure 7b and a Fluke Ti-45, Figure 7c), it is possible to provide an effective estimate of the desired parameters, validated thanks to comparison with tests carried out with a COND1 device, following certified procedures.[11]

FIGURE 6: **DETAIL OF TIRE SECTIONS CUT ALONG THE MERIDIAN PLANE**

FIGURE 7:
(A) THE STABILITE 2017 ARGON-KRYPTON LASER
(B) THE PHOENIX THERMOGRAPHIC CAMERA
(C) THE TI-45 THERMOGRAPHIC CAMERA
(D) THE LASER SPOT ON THE TIRE EXTERNAL SURFACE
(E) A THERMOGRAPHIC CAMERA IMAGE OF THE LASER SPOT ON THE TIRE EXTERNAL SURFACE
(F) A THERMOGRAPHIC CAMERA IMAGE OF THE LASER SPOT ON THE TIRE INTERNAL SURFACE

FIGURE 8: **COMPARISON OF STORAGE MODULUS (E') BETWEEN A COMMON PASSENGER TIRE AND A GT SPORT TIRE**

FIGURE 9: **COMPARISON OF TAN Δ BETWEEN A COMMON PASSENGER TIRE AND A GT SPORT TIRE**

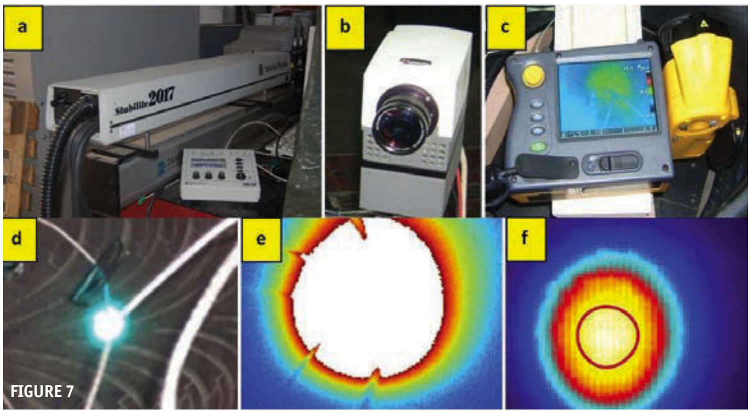


FIGURE 7

The third component is DMA viscoelastic characterization. Tests carried out on sport tires have highlighted interesting aspects, in particular comparing results with common passenger tire ones. Figure 8 shows that, as expected, sport tires are characterized by lower storage modulus values in their optimal thermal working range (35°C and above) that enable them to offer better adhesion and to adapt better to road asperities, optimizing contact area at the price of a lower wear resistance.

Passenger tires are more stable and able to offer good adhesion levels even at very low temperatures, being adapted to the widest possible range of working conditions. Figure 9 shows in a clear plot the possible reason for the so-called 'feeling the grip' phenomenon. Sport tires, as distinct from passenger ones, are characterized by a clear relative maximum at about 42°C and by higher values of tan δ at the usual usage temperatures.

Specifying that the DMA test has been carried out at a frequency of 1Hz, notably different from common tread stress frequencies, a quick calculation, hypothesizing an average road macro-roughness wavelength λ equal to 0.01m and an average sliding speed Vs of 5m/sec, enables the real tire temperature at which the tan δ maximum can be experienced by the driver to be estimated. Applying a simplified version of the WLF equation,[8] it is possible to obtain, which, added to the starting 42°C, gives a temperature of 63.6°C, in accordance with the experimental value shown in the analyses already presented.

$$\Delta T = 8\,(\log_{10}(Vs/\lambda)) = 8\,(\log_{10}(5/0.01)) \approx 21.6^{\circ}C \qquad (1)$$

FIGURE 8

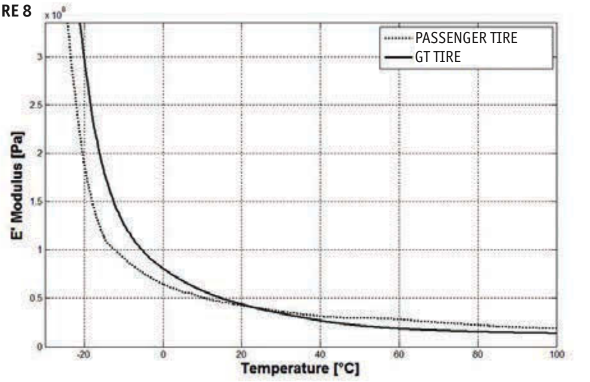
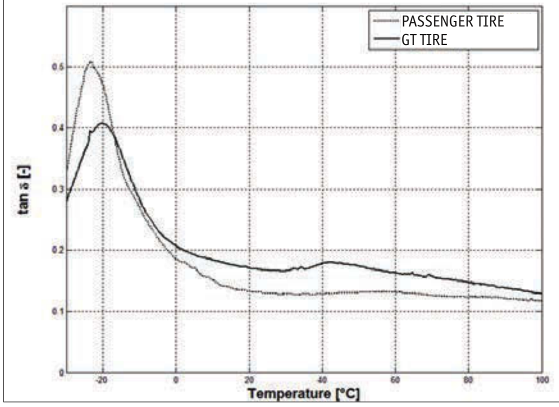


FIGURE 9



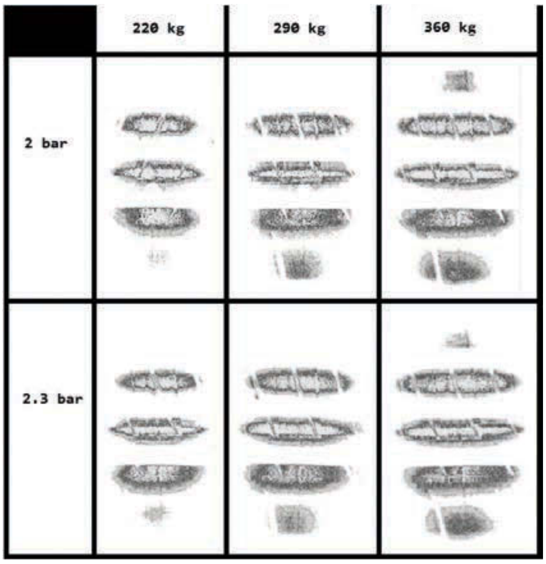


FIGURE 10

FIGURE 10: **SCANS OF A GT TIRE CONTACT PATCH UNDER DIFFERENT TESTING CONDITIONS AT ZERO CAMBER ANGLE. IT IS NOTICEABLE THAT AT INCREASING LOAD THE CONTACT AREA INCREASES, PROGRESSIVELY INSERTING SHOULDERS IN THE INTERACTION ZONE. AT HIGH INFLATION PRESSURE THE CENTRAL RIB IS MORE EXTENDED, WHILE LOWER PRESSURE TENDS TO OVERLOAD THE SHOULDERS**

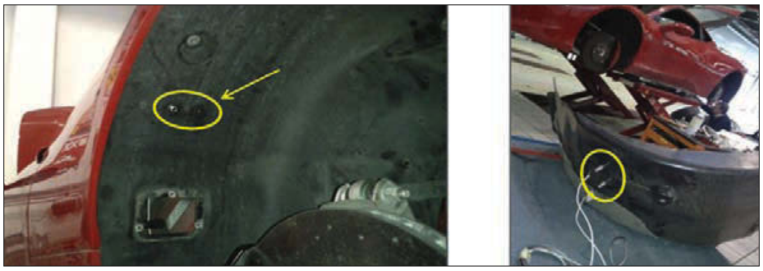


FIGURE 11

FIGURE 11: **INSTALLATION OF INFRARED THERMAL SENSORS AND LOCALIZATION INSIDE VEHICLE WHEELHOUSES**

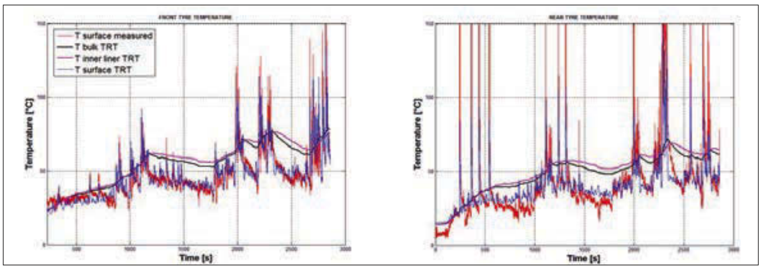


FIGURE 12

FIGURE 12: **TRT RESULTS EVALUATION FOR FRONT AND REAR TIRES**

Non-destructive testing procedures

The first of these to be applied is contact patch analysis. A specific test bench[12] is used to apply a static vertical load to the tested tires, analyzing contact patch extension and pressure distribution. It is possible to interpose pressure-sensitive Prescale sheets between the tire and the flat steel countersurface, and to plan tests at different loads, inflation pressures and camber angles. In Figure 10, the results of a zero-camber testing session on a front tire are reported.

The second is track thermal tests. These sessions are carried out to a specifically developed procedure, with the aim of collecting tire data under various thermal conditions. In order to acquire tire temperature, the vehicle is equipped with infrared sensors installed in the wheelhouses (Figure 11) and directed on the tread surface. The signals are acquired by Dewesoft hardware. Each tire tread is interrogated by two different measurements, particularly useful for front tires, which when steering could be characterized by discontinuous temperature profiles.

After carrying out the track experimental session and acquiring data to be processed by the TRICK procedure, a 'virtual telemetry' is generated.

Speed, slip, camber and force channels are used as input for TRT, whose results are compared with the measured surface temperatures (Figure 12), delivering good correspondence with available data and, very usefully for the grip analysis discussed in the following, an estimation of tire-bulk temperature.

Common analyses concerning the relationship between the tire friction coefficient and temperature are based on the only thermal data experimentally available, i.e. the tire's external (and in a few cases, internal) temperature, measured using a great variety of techniques. A typical correlation between lateral grip and measured temperature appears like that shown in Figure 13, from which very little information can be deduced.

Thanks to the availability of the bulk temperature, it is possible to provide much more useful correlations, such as the ones shown in Figure 14, from which an optimal thermal range can be identified. The reason why the bulk temperature offers better results can be attributed to the fact that the surface temperature varies with very fast dynamics but it is not possible to modify the polymers' characteristics quickly enough to see the response of the whole tire's frictional behavior. Bulk temperature, on the other hand, can be considered to be the tread's core temperature, more resistant to fast variations and directly connected to the rubber's viscoelastic state.

As a further validation of the described procedure, it can be seen that the optimal temperature value is in good agreement with the theoretical result seen in Equation 1 (*see page 29*), confirming that the thermal model can be employed as a predictive instrument to investigate performance optimization strategies and that a proper knowledge of polymer characteristics can be a useful starting point to a better understanding of the dynamics of tire-surface interaction.

TRIP-ID, TRT and GrETA

The thermal and grip models can usefully cooperate, employing the TRT output as an input for GrETA, which can be used to introduce into the Pacejka interaction model the dependencies on temperature, tire working variables, road roughness and compound characteristics.

The advantages coming from the cooperation of these models can be summarized in the following three points, which have already been exploited (further application possibilities are clearly available).

The first is the prediction of tire behavior on the various tracks of a racing championship, each characterized by different roughness (previously measured) and weather conditions.

The next is a performance evaluation of the characteristics of various compounds, which enables a dialog with the tire makers to be established, directing tire construction and compound development to the achievement of a common aim.

The third is the definition of an optimal vehicle setup in terms of wheel angles, load balance and tire inflation, and of driving strategies that are able to reach optimal grip/thermodynamic conditions.

Figures 15 and 16 show the differences between force data from telemetry and from the Pacejka model, whose inputs are the measured slip, load and camber. In the first case the calculated forces are reported as scaled by a Coulomb friction model, always equal to one except for the static value (which means using a standard Pacejka output, with no further processing).

In the second case, the forces are processed with GrETA friction scaling factors, taking into account phenomena neglected in the first case. It can be seen that employing

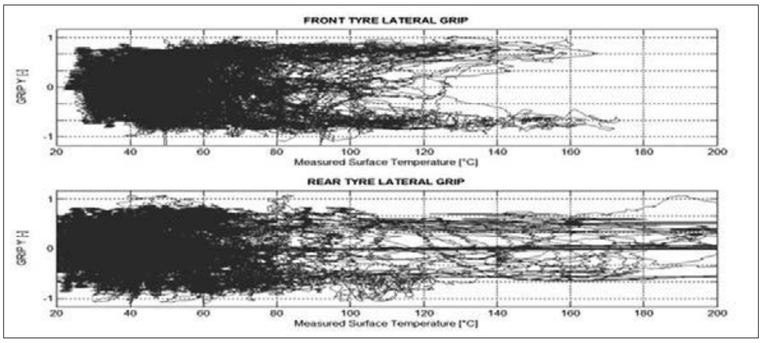


FIGURE 13

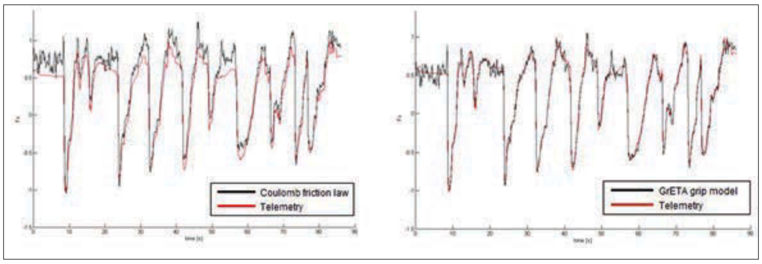


FIGURE 15

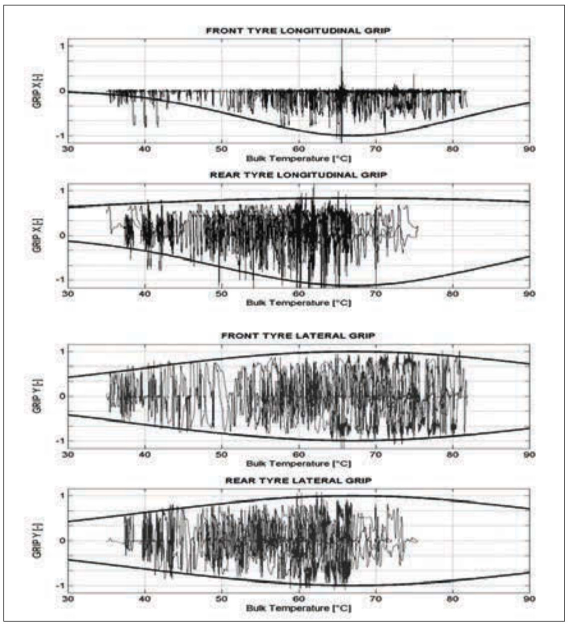


FIGURE 14

FIGURE 13: **FRONT AND REAR LATERAL GRIP REPORTED AS A FUNCTION OF MEASURED TIRE SURFACE TEMPERATURE**

FIGURE 14: **FRONT AND REAR GRIP REPORTED AS A FUNCTION OF TIRE BULK TEMPERATURE ESTIMATED BY MEANS OF TRT. BELL-SHAPE CURVES HAVE BEEN DRAWN TO HIGHLIGHT THE TRENDS**

FIGURE 15: **COMPARISON BETWEEN LONGITUDINAL TIRE FORCES MODELED BY MF WITH A COULOMB FRICTION LAW AND WITH GRETA FRICTION MODEL**

FIGURE 16: **COMPARISON BETWEEN LATERAL TIRE FORCES MODELED BY MF WITH A COULOMB FRICTION LAW AND WITH GRETA FRICTION MODEL**

the grip model produces better results, particularly with respect to longitudinal interaction in the traction phase, which is thermally stressful for high-performance tires and able to generate heat for the friction power mechanism, which induces noticeable effects in tire/road interaction modeling.

Physical interaction model and further developments

The Pacejka model is not the most flexible and detailed method to describe local phenomena of tire/road interaction, but represents a very robust and intuitive solution to obtain the barely achievable aim of modeling tire tangential forces.

For this reason, further developments of the activities discussed in the present work will focus on the realization of a fully physical interaction model that, starting from the knowledge acquired about the topic by the vehicle dynamics research group,[13,14] will be able to interact deeply with the other models, creating an analytical and predictive instrument that can be employed in a wide range of automotive applications.

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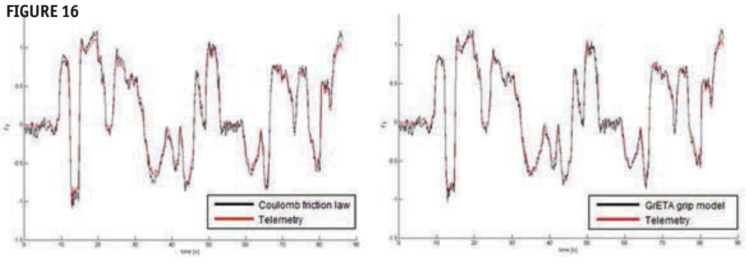
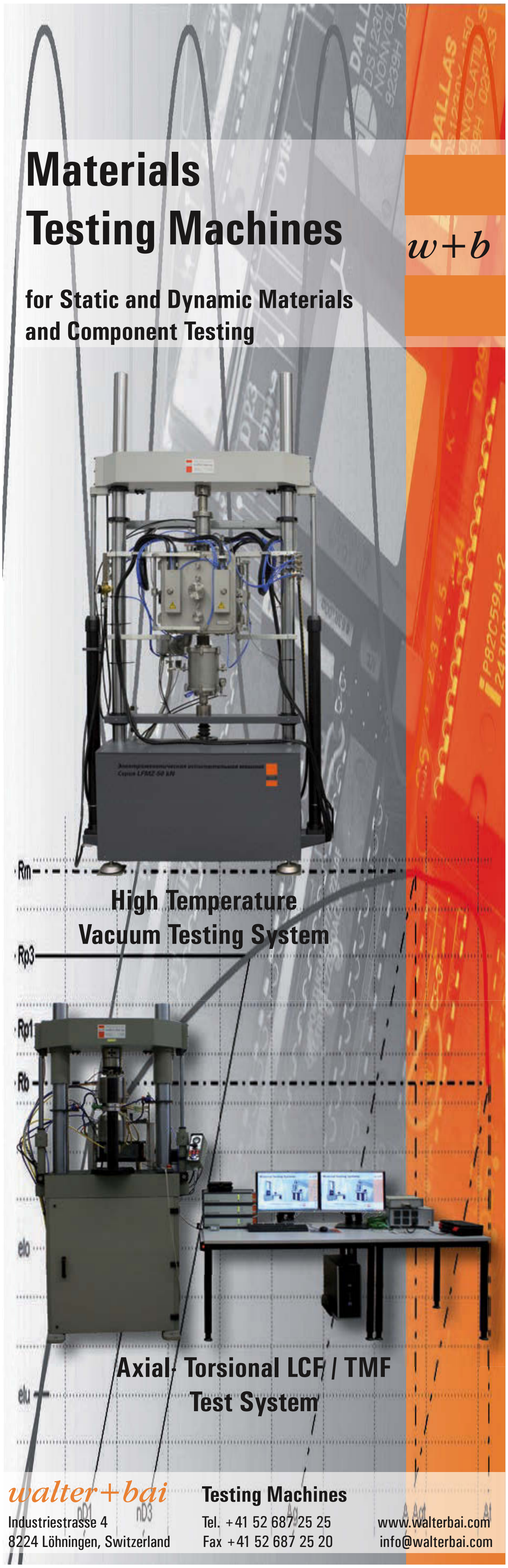
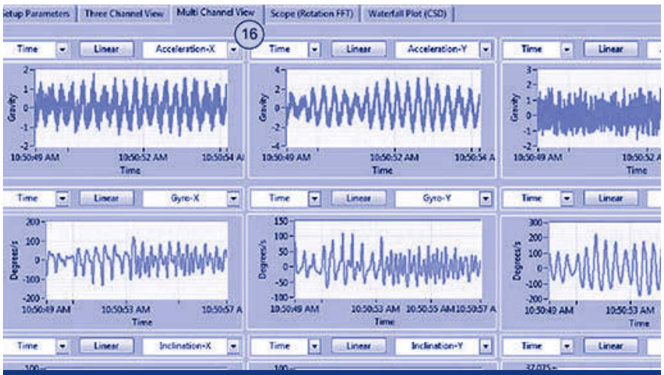
FIGURE 16



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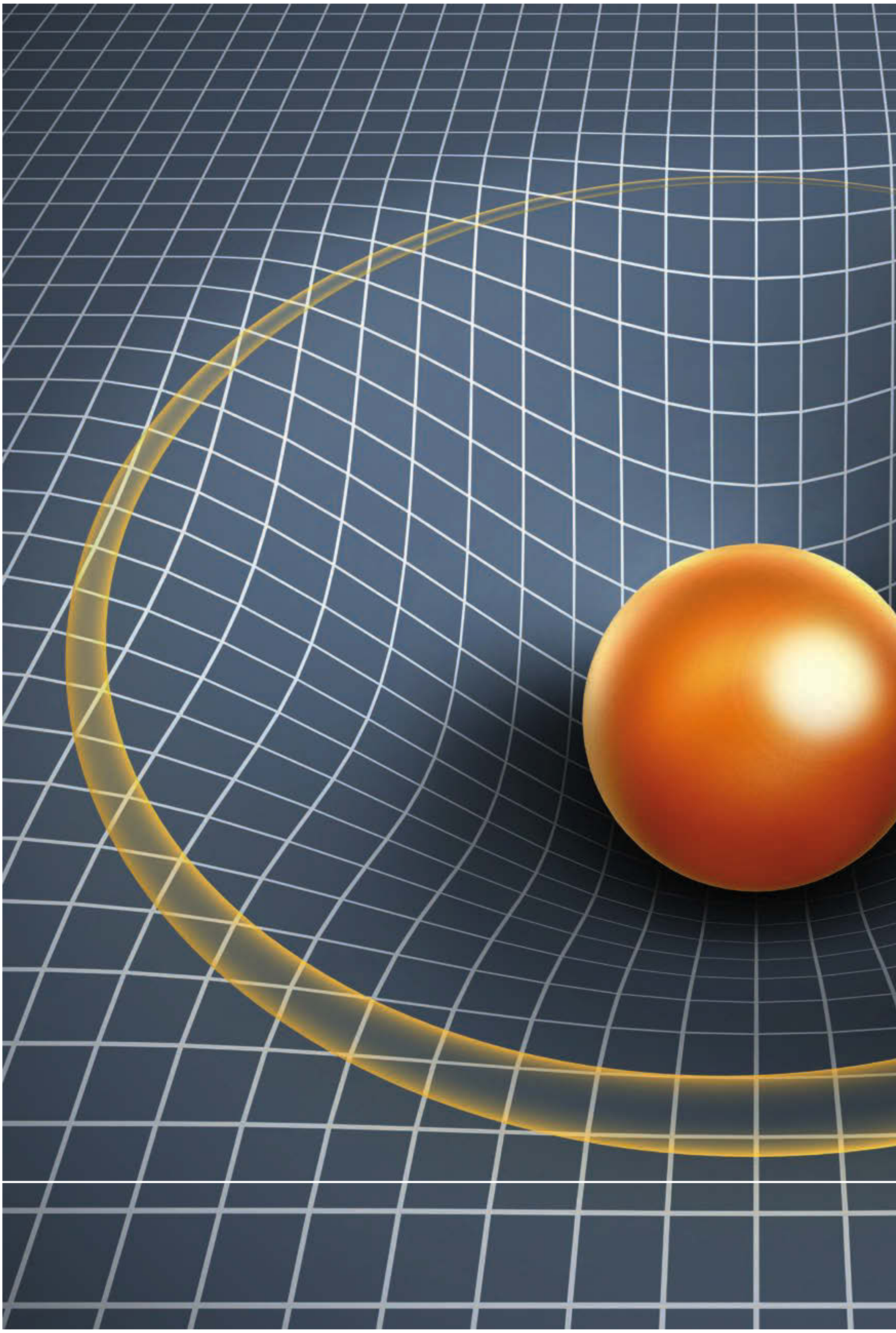
A STUDY INTO VEHICLE CONTROL AND THE INNATE NATURE OF GRAVITY. BY **MAGNUS ROLAND**, S2AB



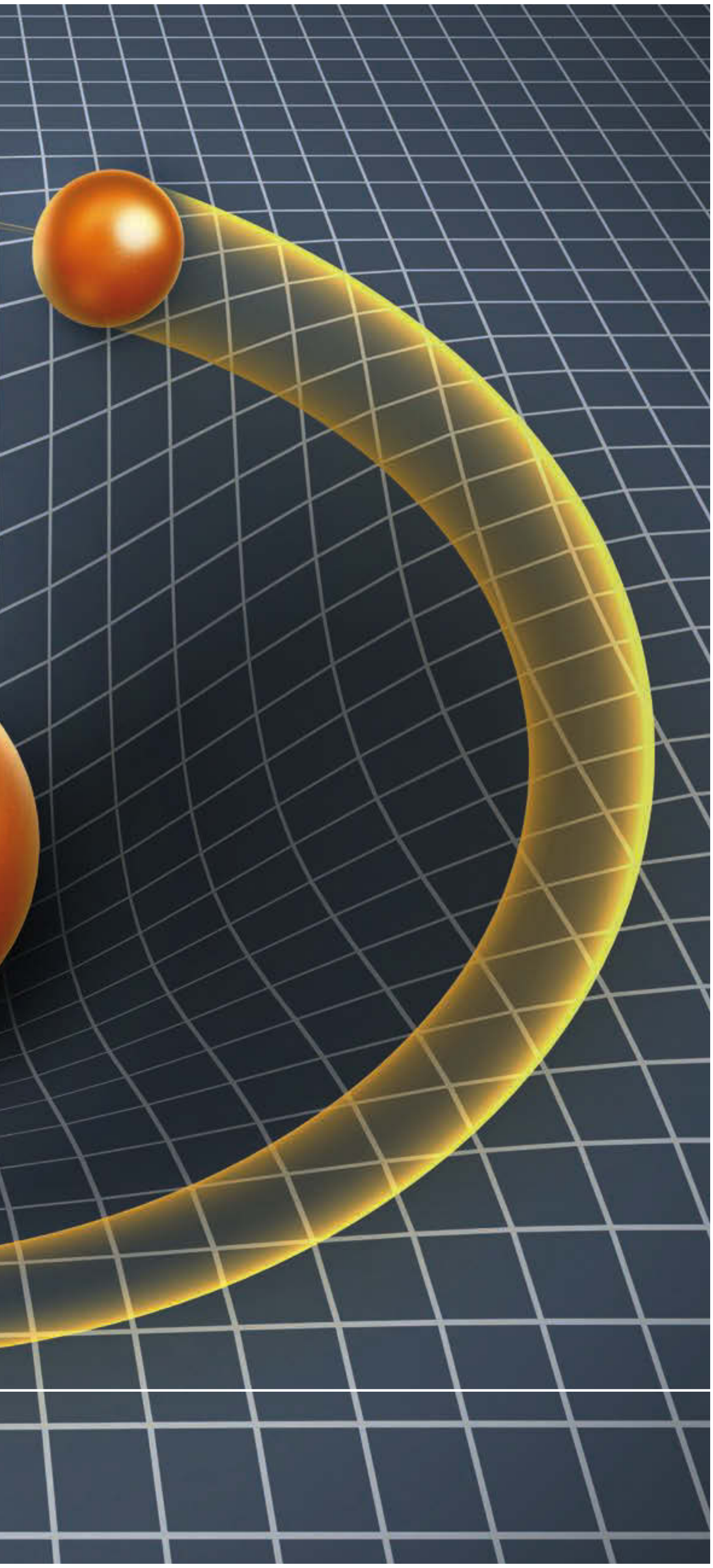
Gravitational

In the May-June 2014 issue of *Vehicle Dynamics International*, John Miles brought up the topic of gyroscopic effects and their crucial role for canceling out destabilizing characteristics in a suspension system. Miles explained the complexity of the synthesized effects of engineering design parameters with one remark: "I can't comment on the multitude of inputs involved and their relative importance or Roland's explanation using quantum mechanics theory."

The average person on the street would agree that you cannot control a car without gravity and a conscious mind. This self-evident understanding should connect to scientific theory, where the Standard Model of Physics explains the interactions of particles and fields, but not the nature of gravity. Mind, thoughts and consciousness explain the fundamentals of metaphysics, where intelligence and thinking is topological. Because the development of geometry preceded the development of topology, and due to historical reasons, our world view continues to be geometrical, including how gravitational effects are caused by the curvature of space and time.

The phenomena of consciousness, mind and the thinking brain forces us into a paradigm which is neither classical nor quantum, but instead connected to information theory and signal processing. This phenomena is leading to modern formulations of physics which use topology and functional analysis to create non-linear field theories for understanding gravity, including how non-linear theory applies to vehicle dynamics, rather than the dominant focus on the more linear control theory of gain factors and response time.

A fundamental principle in Albert Einstein's theory of general relativity



effects

FIGURE 1: **AN ACCELERATED BODY IN A RECIPROCATING POWER RADIATION SITUATION SEES NON-SYMMETRIC PULSE, GIVING BETTER DYNAMICS**

is that acceleration and gravity are indistinguishable. The theory of general relativity redefined gravity, with the space-time curvature replacing the force of gravity as according to Isaac Newton. The concept of geometrodynamics has been defined as the geometry (of space-time), which tells matter how to move, and matter tells geometry how to curve. This sounds similar to another definition, which stated that kinematics (geometry) tell matter (links) how to move, and matter (links) tell geometry (kinematics) how to curve. However, geometry is an effect caused by dynamic motion that is generated by a cause, which in reality is the suspension topology.

No mass of Earth behind a car will pull the vehicle rearwards, and nothing pulls the air rearward. Vacuum energy as a background energy radiation exists in absolute space, and it influences the dynamics of the universe on a cosmological scale – and indeed on all scales. Newtonian mechanics build upon absolute time and absolute space as foundations for inertial frames of reference where time and space are homogeneous and isotropic, and thus time-independent.

Gravity as indistinguishable from acceleration in m/sec^2, and is by dimension a space-time concept. However, neither space nor time can apply force on matter. Therefore, space-time curvature cannot cause effects of gravity, where an active 'force field', interacting with matter on all scales down to and beyond Planck levels and can give effects of gravity globally and locally in singular points. An accelerated body in a reciprocating power radiation situation would create a non-symmetric pulse, which would result in greater dynamics. The high power density of steel means it is pushed backward, just as the lower-power density air is taken into states of higher power density. This phenomena would not have the power to push a plumb line hanging from a balloon forward, but it would have the capacity to push the balloon itself forward. Thus vacuum 'force field' radiation would have the power to cause an effect on the compactness of the plumb and later it will be shown to have sufficient power to affect photons of light.

Sustained dynamics on all scales, from cosmology down to Planck scale and everything in between for the dynamics of a vehicle suspension, have an active interaction. A convoluted integral of physical impulses accumulated over time results in a state whereby inertia has a physical memory. The conservation law defines linear progression into momentum as a physical intention. A mechanical topological suspension system can therefore be defined to operate analogous to the human mind with synthesized quantum states of memory and intention. Such intelligence with proper use of all three principles of linear momentum, energy radiation and angular momentum can have adaptive control capacity of matter in stochastic environments. Advanced levels of vehicle control exposed to stochastic input in the tire-to-road interaction must have a suspension topology that provides the driver with full control of the vehicle's low-frequency harmonics, and cancels out disturbances from stochastic road input.

The implicit stochastic tire camber dynamics of toe-in should be balanced by the equally fast implicit kinematic toe-out. Kinematics, by definition, has implicit instantaneous action if the suspension topology is de-coupled in 6DOF. If not de-coupled, the elastokinematic coupling will distort the signal processing to a low dynamic bandwidth. This perfect destructive interference will give the driver confidence as the signal processing mechanism directs chaotic input into clean signals for all degrees of freedom of motion, including yaw, pitch, roll, warp and lateral acceleration.

FIGURE 2

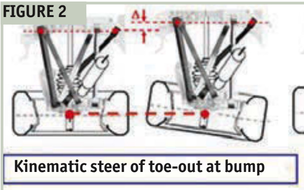


FIGURE 3

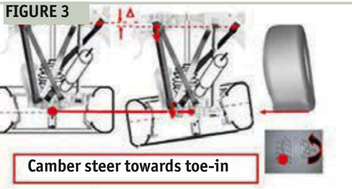


FIGURE 4

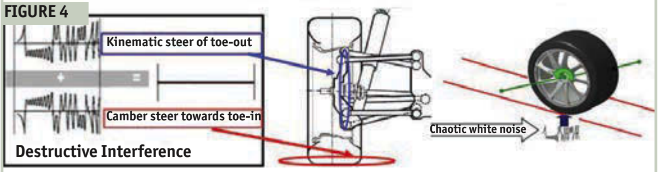


FIGURE 5

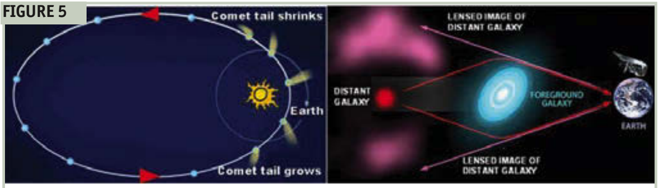


FIGURE 6

FIGURE 2 (TOP LEFT): **KINEMATIC STEER OF TOE-OUT AT BUMP**
FIGURE 3 (TOP RIGHT): **CAMBER STEER TOWARDS TOE-IN**
FIGURE 4 (UPPER MIDDLE): **DESTRUCTIVE INTERFERENCE**
FIGURE 5 (LOWER MIDDLE): **A LENSED IMAGE OF A DISTANT GALAXY**
FIGURE 6 (ABOVE): **CARTESIAN AND EULER COORDINATES**
FIGURE 7 (RIGHT): **THE SCHOOLBOOK EQUATION $A=2S/T^2$ SHOWS THAT A TIRE RUBBER MOLECULE EXPOSED TO A COMPRESSION OF THE TIRE BELT WITH $\Delta Z \sim 22$MM DURING $\Delta T \sim 0.9$MS AT 200KM/H WILL SEE AN EXERTED POWER GIVING 5,500*g***
FIGURE 8 (BOTTOM): **A FORMULA 1 CORNERING CAPACITY LOSS OF 1.3*g* FROM HIGH-SPEED SHAKE**

Mainstream understanding of vehicle dynamics builds upon classical mechanics and objective measures of forces and motions. The above example shows that this understanding is not sufficient. The phenomena of consciousness, mind and intelligent thinking forces us into a paradigm that is neither classical nor quantum, but connected to info-physics, which also relates to gravity, with a justified capacity to guide matter and particles in the open free space when exposed to a chaotic cosmic bombardment. Gravity also has a justified capacity to bend the path of propagating photons. Gravity is no DC-force, a point validated by the observations of high and low tide acting as a shock-absorber, reducing the spin of the Earth at a rate of 0.02ms a year, while the lap-times of the moon's orbit stays constant, with the moon and Earth moving apart 3.8cm per year, while such tidal action causes Earth and the sun to move apart 15cm per year. Transmitted energy in the open space of vacuum energy must take the form of AC-power as the observed Earth-moon attraction is accompanied by radiated power which increases the linear momentum of the moon. Absolute time and space with continued use in classical mechanics also connects to the concept of 'absolute' or 'perfect' pitch. The human capacity of perfect pitch is essential in music. Pitch as an auditory sensation relates to frequency, but the two are not equivalent. Frequency is an objective, scientific observation, whereas pitch is a subjective perception. It takes the human quantum brain and the topological consciousness field of the mind to map the qualities of pitch.

For advanced levels of vehicle control, there is no playing of instruments as the driver is totally integrated with the vehicle as the instrument. A driver's 'perfect pitch' is a capacity to detect complex wave patterns from the interference of superimposed implicit dynamics, where states of 'absolute pitch' with total contact with 'absolute space' generate states of 'flow' with 'absolute control'.

The absolute space-time inertial frame of reference now has been defined as the Higgs field, which takes a constant absolute space-time value, and it cannot be 'turned off'. Defining this element as a Higgs field or a gravitational field, and the active element as a Higgs boson or a graviton may be a matter of taste. The graviton is a hypothetical particle that mediates the effect of gravity. It is expected to be mass-less, similar to the Higgs boson. The innate nature of gravity is proposed to be characterized by 'radiated attraction'. Radiation from sunlight can exert a pressure on comet particles concurrently as the body of the comet seems to be attracted by the body of the sun. However, the effect could be that the body of the sun provides a gravitational shadow, such that the cosmic isotropic field becomes unsymmetric, with power reciprocation exerting pressure on the comet toward the sun. As an analogy, gravitational lensing is an effect of unsymmetric power reciprocation exerting a pressure on propagating photons in the path of a light beam, which causes them to bend.

In the standard model of physics, 'spin' refers to intrinsic angular momentum. According to theoretical physics, it can be shown that any mass-less spin field would give rise to an exerted force, or rather a power spectral density signature with interaction defined by a stress-energy tensor as an implicit action of the gravitational field. Quantum spin or intrinsic angular momentum from wheel spin in absolute space is a matter of magnitude of the same physical principle.

As a vehicle's wheel is one unit, the implicit spin and intrinsic

FIGURE 7

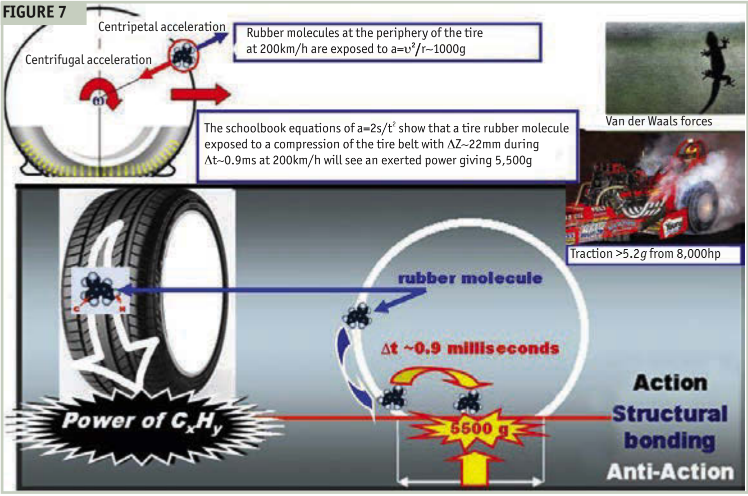
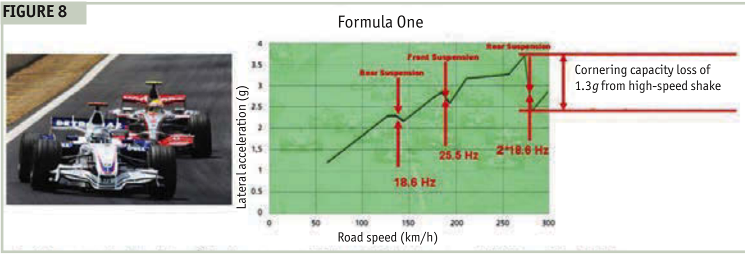


FIGURE 8



angular momentum is one and only one with a phasing of the three defined angles in the Euler reference system to follow well-defined principles for exergetic dynamics. This signal processing is defined by the topology of the five cross-coupled links connected to the wheel-spindle housing.

A wheel with forward velocity, and with the tire footprint compressed in the space of milliseconds, can cause an impact comparable to several thousand *g*. The different mass and momentum of the carbon and hydrogen atoms of rubber give a di-polar effect of structural bonding at an atomic level. Forced Van der Waals interaction of quantum mechanics provides traction magnitudes larger than Newtonian friction F=μN. Top fuel dragsters with no aerodynamic downforce reach > 5*g* acceleration, with the wheels transmitting 8,000Hp over two footprints. The gecko uses a similar mechanism when walking on vertical walls.

Formula 1 cornering capacity as a function of aerodynamic downforce has a lowering effect caused by the high-speed shake of unsprung masses at critical frequencies for front and rear suspensions. At high speed, the drop of 1.3*g* is a loss of 35%. This magnitude cannot be connected to a drop in the normal force in the Newtonian equation F=μN. However, a reduced compression of the tire belt with 3.8mm of the total 22mm at critical frequency is possible. This compression would validate traction as an implicit di-pole effect of structural bonding at an atomic level, with interactions defined by quantum states to be optimized in 6DOF on nano-levels by means of the 'instantaneous action' of the suspension topology.

Serious wobble in road racing or high-speed shake in Formula 1 are effects caused by a change in camber preceding or overriding toe-change from high camber gradients and stiff camber links. The solution has to come from the elastic elements in the camber- and toe-links as the hard-points for the S2AB five-link give a camber gradient of ~3.3°/100mm, which is significantly higher than the toe gradient of ~0.16°/100mm. It is counterintuitive to demand soft bushings in the camber links, as high camber stiffness is required. However, toe-out at a bump is what gives very high dynamic camber stiffness from gyroscopic effects, which overrides and outperforms any kind of soft camber link. The mainstream toe-in at bump will always give a loss in dynamic camber stiffness.

The dynamic bandwidth of mechanical systems can be understood from how the indicated power of a Honda Big Bang demonstrates a controlled powerslide thanks to modulated longitudinal implicit power-pulses of Δt = 0.0007sec, with safe cornering from lateral implicit traction power-pulses of Δt = 0.0025sec actively modulated with a frequency of 300Hz. For reference, modern ESP systems with electronic intervention are acting at 10Hz by means of explicit reactive sensory feedback.

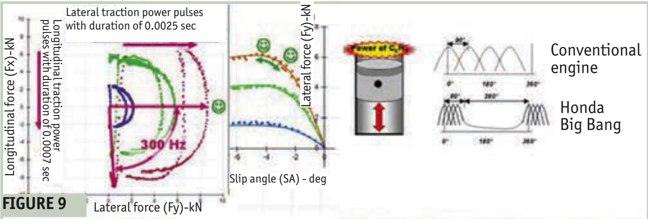
In 1993, McLaren made a presentation which stated that high-speed shake from precession can be avoided with camber gradient for roll compensation of only ~60%. S2AB has valid experience that a correctly engineered topology provides robust dynamic harmony for toe and camber phasing, and also for full roll compensation. This demands that toe-out at bump precedes camber at bump for extremely small amplitudes and for instantaneous action from the gyroscopic nutation, which in fact is the cause of the observed precession.

A spinning wheel with gravity acting on the mass around the point of an attached string can change the spin axis downward (Figure 11). A camber change (picture 1: A) creates motion that generates instantaneous gyroscopic moment to change the spin axis rearward; a toe change at (2: A) generates an instantaneous gyroscopic moment to change the spin axis upward; and returns (3: A) to its original horizontal position (1: A).

The instantaneous action of nutation as a spin-axis motion between states of toe and camber is a motion with extremely small amplitudes and extremely high frequencies. The spin axis is observed to remain horizontal while the effect caused by nutation is the observed precession in (3) and (4). The precession of the wheel is also a change of toe, but with a much lower frequency.

To apply the reasoning from Figure 11 pictures 1 to 4 to a suspension is not easy because, rather than exposure to the field of gravity of 1*g*, the impacts in the vertical direction on the tire are stochastic impulses with a superimposed 400Hz of several thousand *g*. The rotating wheel of the rear suspension does not have a fixed point in a string, but 10 points with five links defined as an adaptive controller with instantaneous action from the correctly directed power pulses over the entire suspension.

Finally, the virtual king-pin axis, apart from passing through the drive joint in order to avoid torque steer, must have an inclination and location rear of the wheel center to give the desired gyroscopic effects for the spinning wheel with a superimposed forward velocity. The higher the velocity, the higher is the risk for instability due to high-speed shake, which is clearly seen in Figure 13, which shows the cornering capacity for Formula 1.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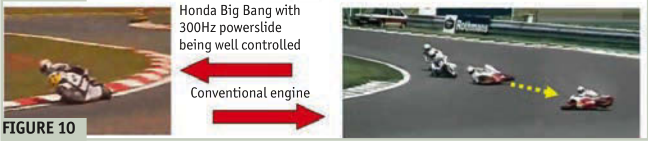
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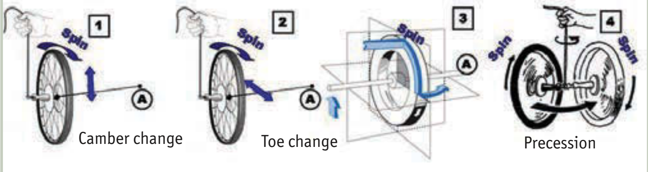


FIGURE 11

FIGURE 9 (TOP): **LATERAL TRACTION POWER PULSES WITH DURATION OF 0.0025 SEC**

FIGURE 10 (MIDDLE): **HONDA BIG BANG WITH A 300HZ POWERSLIDE BEING WELL CONTROLLED (LEFT), AND WITH A CONVENTIONAL ENGINE (RIGHT)**

FIGURE 11 (ABOVE): **A SPINNING WHEEL WITH GRAVITY ACTING ON THE MASS AROUND THE POINT OF ATTACHED STRING CHANGES THE SPIN AXIS DOWNWARD – A CAMBER CHANGE**

FIGURE 12 (BELOW): **THE ROTATING WHEEL OF THE REAR SUSPENSION HAS 10 POINTS WITH FIVE LINKS**

FIGURE 13 (BOTTOM): **VIRTUAL KING-PIN AXIS, SHOWING CORNERING CAPACITY FOR F1**

FIGURE 12

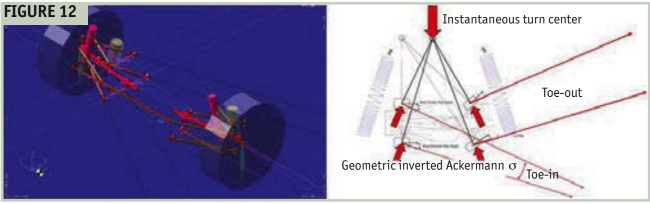
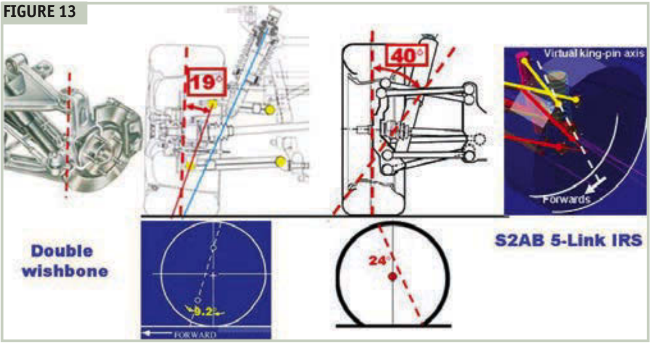
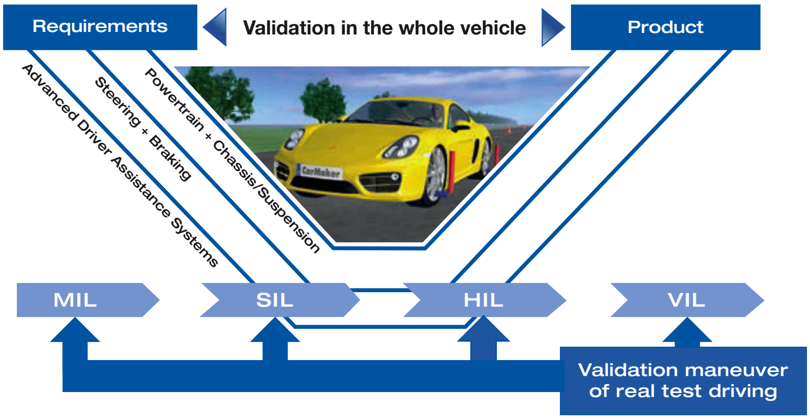


FIGURE 13




Requirements
Validation in the whole vehicle
Product
Advanced Driver Assistance Systems
Steering + Braking
Powertrain + Chassis/Suspension
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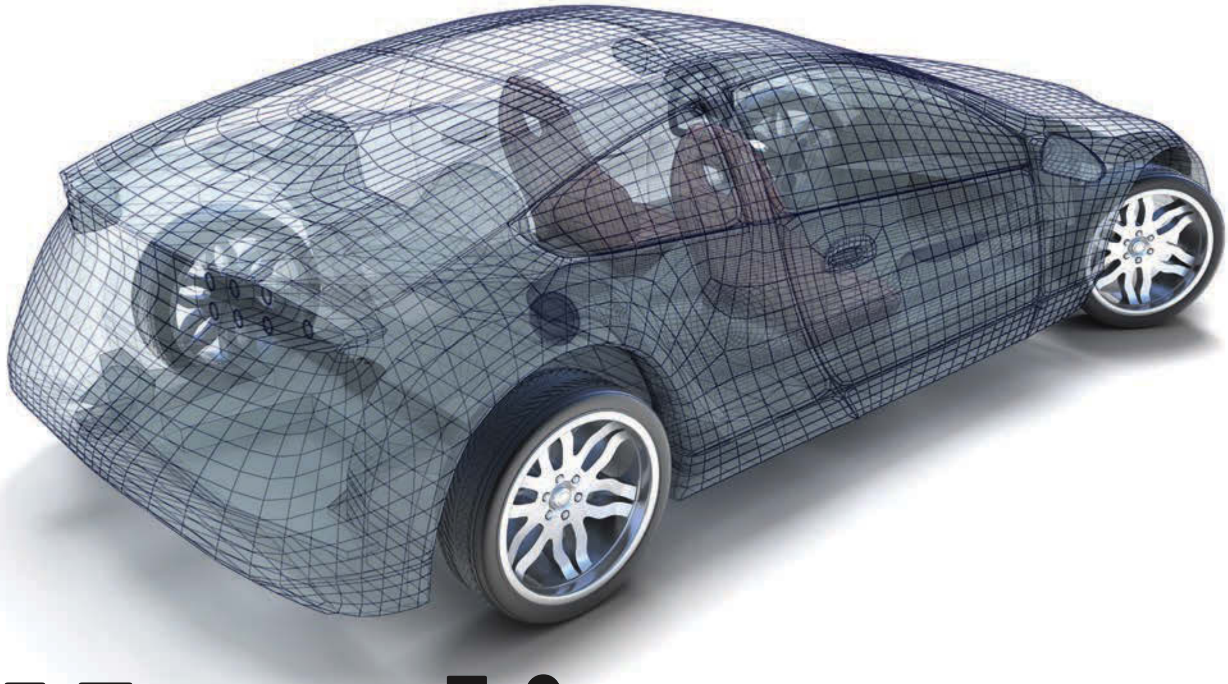


Non-linear modeling

NOSEM, STC, DVS: INNOVATIVE NON-LINEAR MODELING, VIRTUAL SENSING AND CONTROL TECHNOLOGIES FOR VEHICLE DYNAMICS APPLICATIONS.

BY **MARIO MILANESE** AND **ILARIO GERLERO**, MODELWAY

The problems of modeling, control and identification of complex and non-linear systems will become even more pressing in the future of vehicle dynamics. Indeed, in order to advance and optimize current vehicle dynamic technologies, researchers and technicians have to deal with the non-linear behavior of the systems, with related increases in the time and costs of designing and calibrating mathematical models and control algorithms.

Modelway has developed three proprietary technologies – NOSEM, DVS and STC – in order to help dynamics engineers efficiently deal with modeling, virtual sensing and control, respectively, enabling a systematic approach for complex and non-linear systems. These technologies are based on the Set Membership Inference Theory developed at Politecnico di Torino by Prof. Mario Milanese (the author of this paper) and his research team.

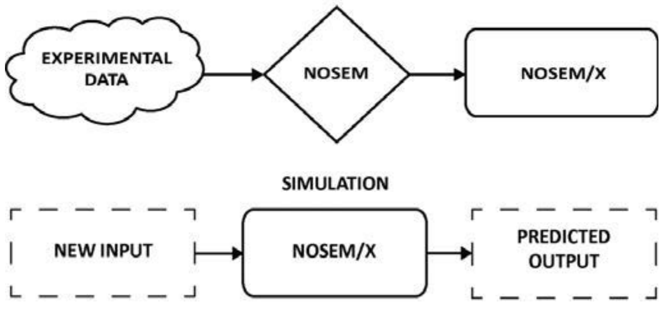
NOSEM (NOnlinear SEt-membership Modeling) is a technology for modeling complex non-linear systems from data. The NOSEM/X model is designed from input-output data measured on the system without requiring extensive use of first principle laws. The NOSEM/X model enables simulation of the behavior of SISTEM X for new input (see Figure 1).

The main features of NOSEM technology are that it can handle systems whose physical description is not well known or is very complex; the accuracy of the designed model is evaluated by guaranteed error boundaries; it is not necessary to search for a model parametric form of non-linearities; and it enables great reduction in the time and costs of model design.

As an application of NOSEM vehicle vertical dynamic modeling, the team developed a mathematical model for

FIGURE 1 (BELOW): **MATHEMATICAL MODELING FORMS EXPERIMENTAL DATA USING NOSEM. THIS IMAGE DEPICTS THE DESIGN AND SIMULATION OF THE MODEL**

FIGURE 1



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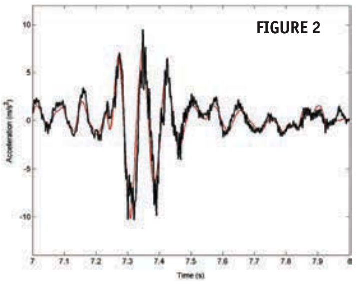

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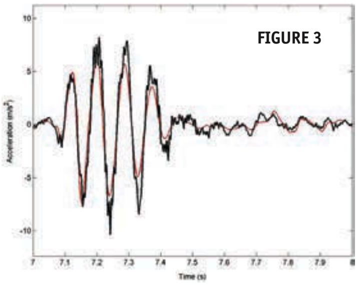


the vertical dynamics of a segment C car with a semi-active suspension. The experimental data used to design and validate the mathematical model was measured on a four-post test bench. The variables used to identify the model are the control currents of the front and rear suspension, with the front and rear chassis vertical positions taken as inputs, while the front and rear chassis vertical accelerations were outputs.

A comparison between the vehicle chassis acceleration as simulated by the NOSEM model and the physical acceleration as measured on the vehicle test bench are shown in Figures 2 and 3 for the front and rear chassis, respectively. The front and rear chassis accelerations have been modeled to obtain the root mean square errors (RMSE) of about 1.2m/s². The model enables its users to obtain quite accurate simulations of a chassis's vertical accelerations under different road profiles and control currents.

The accuracy of the model enables efficient tuning of control algorithms in the computer simulation environment, reducing the need for expensive in-vehicle tuning. The NOSEM model has actually been used to design and test the fast model predictive control (FMPC) system for vehicles with semi-active suspensions[1].

Direct virtual sensing (DVS) is a technology for designing virtual sensors directly from data that has been measured on a prototype vehicle or provided by a reliable simulation. The DVS/X virtual sensor estimates – in real time – the values of variable x from the measurements of the real-time variables available on the system (see Figure 4).

Features of DVS technology include the ability to design the virtual sensor directly from experimental data, which reduces realization time and cost; accurate estimation of the variables of complex non-linear systems without requiring expensive model-building phases; the ability to replace virtual sensors with real sensors when required due to physical or economic constraints; and that robust performance can be achieved even under varying system operating conditions.

The vehicle side-slip angle is one of the most important variables to consider when evaluating vehicle dynamics. The potential value of such a variable for obtaining notable improvements over current stability control systems is widely recognized. However, its direct measurement requires the use of complex and expensive devices (Datron), which cannot be used in production cars.

The purpose of the project was to estimate the side-slip angle based on measurements of yaw rate, lateral and longitudinal acceleration, wheel speed and steering angle, which are available from the ESC sensors in most current production cars. The key innovation of the technology is that the DVS/SA (DVS for side-slip angle estimation) is taken directly from the experimental data collected from a physical test vehicle, which is subjected to appropriate maneuvers (steering angle steps, lane changes, curved tracks), as well as different speed and operating conditions (dry and wet roads, different tire wear and pressure).

In Figures 5-8, some of the results achieved by the DVS/SA are shown, together with the data related to estimation accuracy. In particular, Figures 5 and 6 are based on a curved track with a dry road, performed at a maximum vehicle speed of 200km/h (124mph). Figures 7 and 8 are based on a curved track with a wet road, performed at a maximum speed of 115km/h (71mph).

The estimation error performances of the curved track with dry road are a mean of -0.15°, a standard deviation (SD) of 0.78° and a 90% confidence interval of 1°.

FIGURE 4

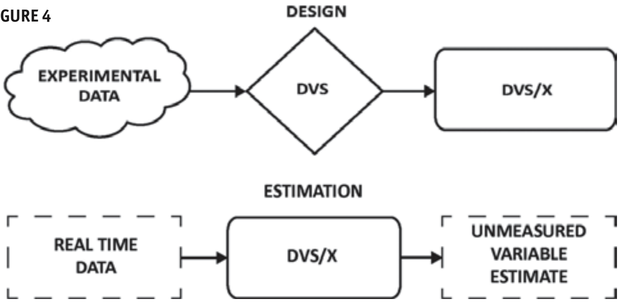


FIGURE 2 (LEFT UPPER): **FRONT CHASSIS ACCELERATION FOR ENGLISH TRACK ROAD PROFILE: MEASURED (BLACK LINE) AND SIMULATED BY NOSEM (RED LINE)**

FIGURE 3 (LEFT LOWER): **REAR CHASSIS ACCELERATION FOR ENGLISH TRACK ROAD PROFILE: MEASURED (BLACK LINE) AND SIMULATED BY NOSEM (RED LINE)**

FIGURE 4 (ABOVE): **VIRTUAL SENSOR DESIGN FROM EXPERIMENTAL DATA USING DVS, DESIGN AND SIMULATION**

The estimation error performances of a curved track with a wet road are a mean of 0.22°, a SD of 0.95° and a 90% confidence interval of 1.5°.

The results of the experiment demonstrated that the DVS/SA can provide robust estimation accuracy, even given the variables of road grip (wet or dry), road type (racetrack, urban or extra-urban), driving style (sport or normal) and tire wear. Furthermore, having knowledge of the real-time value for the side-slip angle enables vehicle stability performance to be improved in terms of cornering control, traction control and lateral dynamics.

The project confirmed that DVS technology can provide effective DVS/SA estimates for efficient side-slip-based control, and for this reason the DVS/SA has been embedded on a recently launched car[2].

FIGURE 5

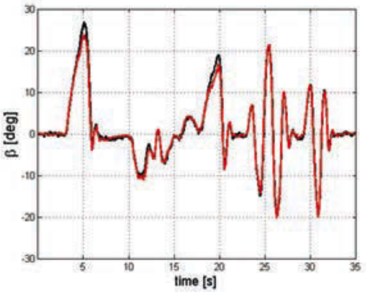


FIGURE 6

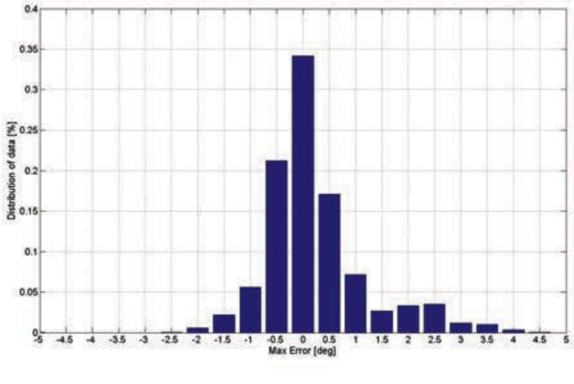


FIGURE 5 (LEFT): **CURVED TRACK WITH DRY ROAD, DATRON MEASUREMENT (BLACK); DVS ESTIMATE (RED)**

FIGURE 6 (BELOW): **CURVED TRACK WITH DRY ROAD, ESTIMATION ERROR DISTRIBUTION**

FIGURE 7 (RIGHT): **CURVED TRACK WITH WET ROAD, DATRON MEASUREMENT (BLACK); DVS ESTIMATE (RED)**

FIGURE 8 (BELOW): **CURVED TRACK WITH WET ROAD, ESTIMATION ERROR DISTRIBUTION**

FIGURE 9 (BELOW MIDDLE): **NON-LINEAR CONTROL DESIGN FROM EXPERIMENTAL DATA USING STC, DESIGN AND SIMULATION**

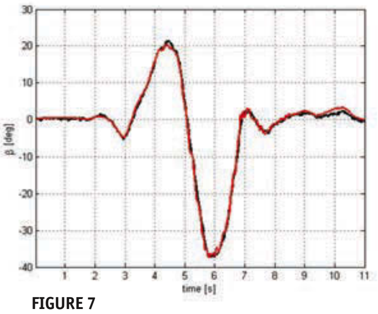


FIGURE 7

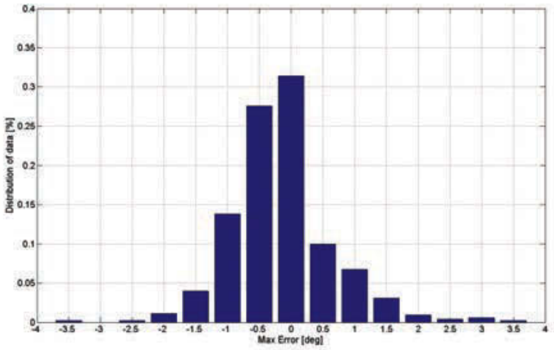


FIGURE 8

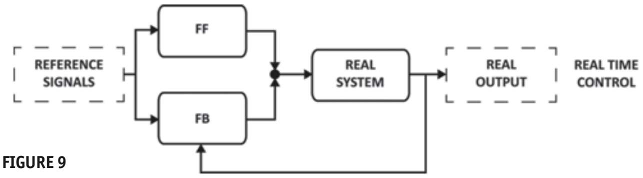


FIGURE 9

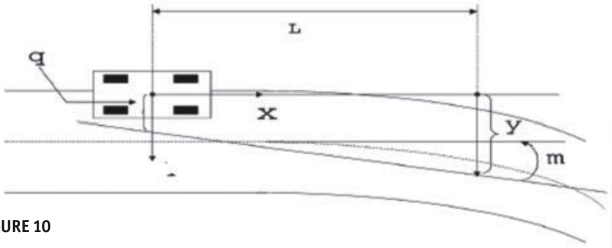


FIGURE 10

FIGURE 10 (ABOVE): **REFERENCES OF THE PLANT TO BE CONTROLLED**

FIGURE 11 (RIGHT UPPER): **DRIVER'S DOUBLE LANE-CHANGE MANEUVER**

FIGURE 12 (RIGHT LOWER): **VEHICLE FEEDBACK POSITION Y**

Self-tuning control (STC) is a technology that enables users to design non-linear control systems directly from data that has been measured on the real-world system or provided by a reliable simulator. The controller can be designed to operate as a feedback and/or feedforward architecture (see Figure 9).

Features of STC technology include having automatic control that is systematically designed from data and does not require deep and detailed first-principle law studies; controllers that allow limited laboratory calibration activities; a major reduction in the times and costs of control system development; and robust performances in the face of variable system operating conditions.

In one project, STC was applied for ADAS for a combined lane-keeping and steering system. The purpose of the project was to design a lane-keeping control system with feedback, giving the driver complete control of the vehicle's lateral dynamics through the steering wheel. The main difficulty of the system was in combining automatic lane-keeping and steering for obstacle avoidance, with lane-change maneuvers for overtaking, and with any other desired maneuvers through a closed-loop control strategy.

The automatic lane-keeping control loop is never opened, and no on/off switching strategy is used. During a lane-change maneuver the vehicle's lateral dynamics are controlled by the driver via the vehicle's steering system. When there is no steering input from the driver, the vehicle's center of gravity tracks the center of the lane in which the vehicle is traveling, using the automatic lane-keeping system. When the maneuver is complete, the lane-keeping function resumes safely and smoothly. The proposed control strategy has been designed based on the assumption that the vehicle is traveling along highways and is equipped with EPS, a vision system and a steering torque sensor.

The controller has a two degrees of freedom architecture. The lane-keeping control operates as a feedback of $y(t)=q(t)+m(t)*L$, where $q(t)$ and $m(t)$ are provided by the vision system, while L is a given look-ahead distance (Figure 10).

Figure 11 shows the experimental results for a test performed on a curved highway track with a radius of 800m are reported. The driver made a double lane change and then released the steering wheel, while the lane-keeping function tracked the car back to the center of the lane (Figure 12).

As lane-keeping control develops, it needs to be operating at all times, with no switching strategy used. The driver can steer as if the automatic control is not there, and if for any reason the driver does not turn the steering wheel, the system will smoothly track the car back to the center of the lane[3].

Further innovative vehicle dynamic applications are currently being investigated, including the application of NOSEM to non-linear tire dynamics modeling; the application of DVS to road-tire friction coefficient estimation; and the application of STC to side-slip angle based on a vehicle stability control (VDC) design.

References:

1) M Milanese, C Novara and A Fortina, 'Experimental modeling of controlled suspension vehicle from onboard sensors'. Vehicle System Dynamics, Vol. 45, No. 2, 2007

2) M Milanese, I Gerlero and C Novara, 'Effective vehicle sideslip angle estimation using DVS technology', SAE Technical Paper, Detroit, 2014-01-0084, 2014, doi: 10.4271/2014-01-0084

3) M Milanese, V Cerone, D Regruto, 'Combined automatic lane-keeping and driver's steering through a 2-DOF control strategy', IEEE Transaction on Control Systems Technology, Vol. 17, No. 1, January 2009

FIGURE 11

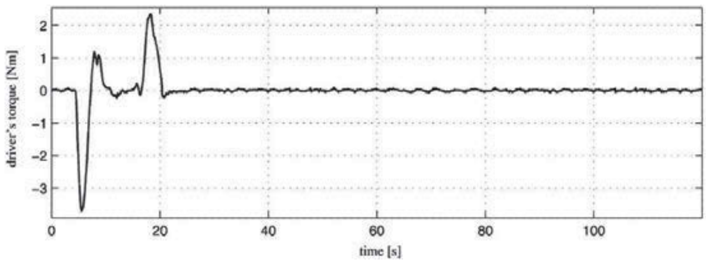
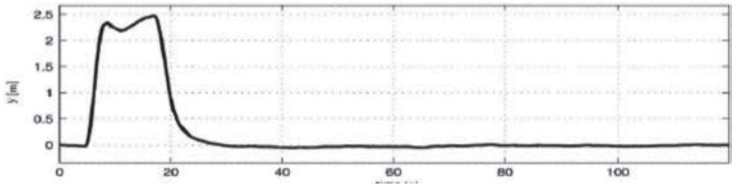


FIGURE 12

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Braking the trend

CAPARO AP EXPLAINS THE CHALLENGES OF NEW PRODUCT DEVELOPMENT AND THE RAPID TRANSITION TO TIER 1 MANUFACTURING

ABOVE: **CAPARO'S T1 HYPERCAR BENEFITED FROM CVT'S HIGH-PERFORMANCE BRAKING SOLUTIONS**
INSET: **THE CAPARO CALIPER DESIGN CONCEPT**

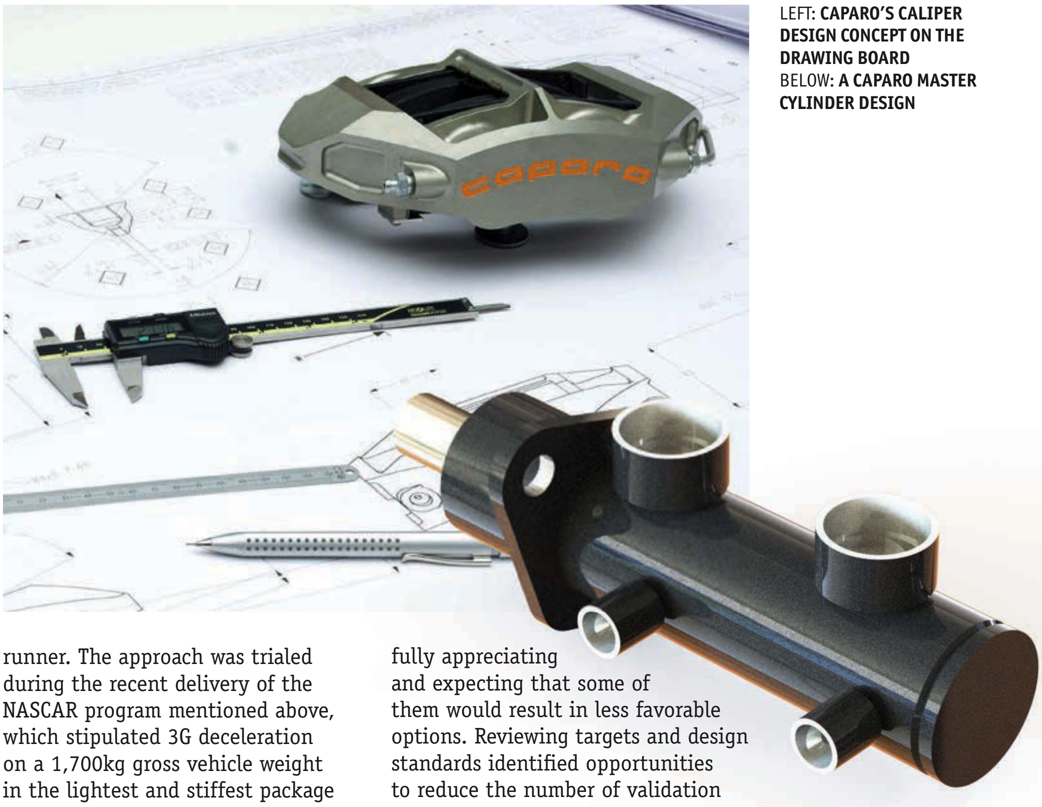
Incorporating a highly responsive and adaptable business within the core operations of volume manufacturing has long been a goal for many organizations. Caparo Vehicle Technologies (CVT) has set out in a new direction to achieve this objective, delivering a new line-up of flexible technology- and engineering-led solutions, while retaining hard lessons learned through more than 85 years of producing automotive Tier 1 and Tier 2 brake systems.

CVT, the company behind the Caparo T1 and T1 Evolution hypercars, has recently merged its resources with Caparo AP Braking (formerly part of the Automotive Products Group), and its initial focus has been on the rapid development and commercialization of technology-led brake systems for platforms produced at a rate of fewer than 100,000 units per annum.

Spearheading this diversification, Anthony Blackwell, director and general manager of CVT, has taken a motorsport-inspired approach and embedded a series of reactive and flexible processes within the workings of volume manufacturing. "Our targets are well understood in the industry, but delivering the result can be a lot harder than it seems," he explains. "As a business we recognized the need to evolve rapidly in order to address the growing challenges and competition within the brakes sector. To meet this need we have integrated our motorsport knowledge with Caparo's core industrial manufacturing expertise to deliver a series of rapid new product developments."

The results speak for themselves as CVT has managed to greatly accelerate its brake caliper design process. The traditional approach usually requires around 12 months to complete, but Caparo has succeeded in introducing five new caliper concepts into NASCAR – one of the world's most technically demanding brakes applications – while also unveiling five further new product concepts, with a further two new upgrades launching in the next six months.

"We identified specific product requirements that meet the needs of future platforms and, breaking from tradition, started multiple, complementary product developments simultaneously. We focused heavily on design integration, transferable components and flexible assembly to reduce parts count and increase efficiency, to reduce both the complexity and technology risk of each new development. This synergy has enabled us to create a product range that offers a combined effect far greater than the sum of each individual part," says Blackwell.



LEFT: **CAPARO'S CALIPER DESIGN CONCEPT ON THE DRAWING BOARD**
BELOW: **A CAPARO MASTER CYLINDER DESIGN**

"Some of the products are, on the face of it, commonplace, such as our electrically actuated spot caliper, integrated opposed piston park and service brake, or the compact ABS master cylinders," he continues. "Our new design interpretations, however, offer substantial benefits and we believe the level of integration with our industrial manufacturing capability provides commercial and technical advantages for customers. Developing multiple new products in parallel was also a unique opportunity to integrate common features and design compatibility across a range, which would otherwise have been impossible."

So how was all this achieved? To begin with, CVT adopted a different process for managing projects, one that was not based on a remote and separated project management function, but focused on a dedicated engineer-led front runner. The approach was trialed during the recent delivery of the NASCAR program mentioned above, which stipulated 3G deceleration on a 1,700kg gross vehicle weight in the lightest and stiffest package possible, and brake disc temperatures exceeding 1,400°C. CVT is familiar with managing aggressive stopping power, achieving 100mph to 0 in just 2.2 seconds during the design and production of the T1. However, the NASCAR application took the thermal challenges to a new level, particularly with aluminum calipers because the material is susceptible to softening at relatively low temperatures.

The timescale (five new caliper concepts in five months) provided an opportunity to test the new methodology 'in action'. Caparo's view was that while project management defines deadlines, all too often it also results in a mindset that measures and identifies reasons for introducing delays. Hence the new approach was to set the deadline with the goal of achieving it.

This approach entailed a step-change within the business with new, less-rigid processes and a more creative approach to problem solving. In the NASCAR case, CVT initiated the simultaneous use of multiple analyses and exploration routes, fully appreciating and expecting that some of them would result in less favorable options. Reviewing targets and design standards identified opportunities to reduce the number of validation steps, and although some of the decisions taken may have been viewed as high risk in the traditional automotive environment, they were identified and evaluated in parallel, ensuring the process was not delayed and designs not compromised.

The fundamental design principles of brakes have remained unchanged for years. Systems have always demanded light weight and high stiffness to deliver the necessary stopping power, while reducing unsprung mass and enhancing a vehicle's dynamic characteristics. This trend is even more pronounced in the performance sector today, and an increased focus on emissions and improvements in materials means that lightweight design requirements apply just as strongly.

Mass targets can easily be achieved by accepting an associated compromise in deflection or fatigue. However pedal feel is a key characteristic, giving the driver the confidence to brake late and hard, delivering improved vehicle performance. A caliper must react

TOP: **CAPARO'S T1 HYPERCAR UTILIZED AN ADVANCED CAPARO BRAKE CONCEPT**
ABOVE: **CAPARO ALSO HAS EXTENSIVE MACHINING CAPABILITIES**

against pad drag loads (the action of trying to pull the pads around the wheel during braking) and clamp loads (the force generated by hydraulic pressure behind the pistons). High deflection will have the effect of increasing the fluid volume necessary to deliver the equivalent clamp loads, which will be required in a stiffer caliper. This effect invariably gives the feeling of a 'soft' pedal, which reduces driver confidence. To deliver the required level of performance for NASCAR, Caparo defined a maximum design deflection of 0.18mm, down from road car tolerances of 0.25mm.

Embracing the latest in advanced topological optimization tools, the business greatly reduced the iterative design steps required. At the same time, the results of these steps had to be validated and at best considered as guidance, while thermal management introduced its own parameters. To compress timescales, Caparo decoupled the thermal and stress analysis conditions and focused more on passive thermal management measures. On the face of it, this may have been a major risk in such a high-performance application. However, as the extreme temperatures seen were local to the disc surface, radiant and conductive heat could be characterized and managed separately. Analysis identified key hot spots on the caliper body, while thermal barriers were adopted to reduce transmission through conduction. This approach does not reduce the level of validation, and it maintained the very tight delivery deadlines for the initial design release. Ceramic-coated piston caps offered protection between the pad and the pistons ensured that heat conduction to the brake fluid was minimized. In order to promote surface cooling, air paths were introduced between the piston and the caps, enabling circulation of air within the caliper pistons and behind the thermal caps.

"For those familiar with race brake applications, many of the steps taken will be a given and will be achievable in this environment. What is interesting is that we have achieved our goals within the core operations of Tier 1 supply. Backed by Caparo's wider Tier 1 systems and experience, the project has now transitioned from prototype to manufacture on one of our production cells," adds Blackwell. "We believe that what defines Caparo Vehicle Technologies is the ability to create high-technology products, developed in this environment using our industrial manufacturing capability, providing the best of both worlds."

Using the 'industrial merge' and a streamlined development process, combined with a highly commercialized focus, CVT is in the advanced stages of development with multiple concepts, such as a range of master cylinders with variable capacity for mainstream automotive applications supporting maximum flexibility through minimum components; parking brake systems compatible with both mechanical and electrical actuation; an integrated, opposed piston parking brake caliper that reduces the brake envelope compared with other available solutions in the market; and new ideas for the use of non-metallics in caliper designs.

CVT's new compact ABS system, for example, offers not only an enhanced product but also uses the core of Caparo – its steel business. Where much of the market has moved to the use of aluminum, CVT is embracing the use of steel within its new products and has created early prototypes enabling highly flexible manufacture and assembly. The specific design features used to achieve these claims are still under wraps; however, the company can say that the principle enables multiple master cylinder configurations and capacities from a single, common tube section.

"The transition from prototype to volume production is one that often presents the greatest challenge during the initial specification and design stage for each product, and the goal is to establish common design features, enabling a reduction in parts count and an increase in the modularity of design, enabling multiple variations through a single component change. The company is aiming to harness the capabilities of the wider Caparo Group. One thing is certain – we will continue to evolve, innovate and grow as a business; this is just the start of a new and exciting chapter," states Angad Paul, chief executive officer of Caparo.

"With the recent announcement of a €4m investment plan we have already taken steps to ensure that products manufactured by Caparo are not only priced competitively but are also technologically one step ahead," adds Paul. "We are ready and able to manufacture client-specific solutions that can be incorporated directly into the production line – such as full corner assemblies, or even an entire chassis."

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Effective code generation

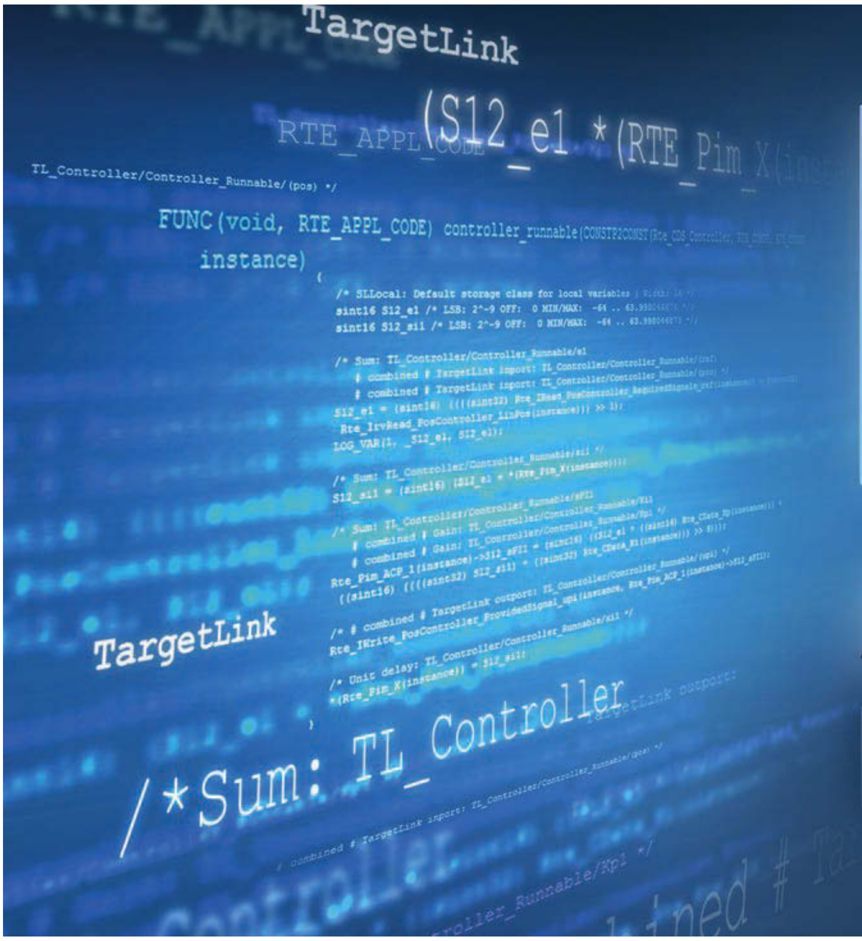
DSPACE HAS CONTINUED ITS DEVELOPMENT OF TARGETLINK, ITS PRODUCTION CODE GENERATOR, TO ENSURE IT REMAINS AN INDUSTRY BENCHMARK

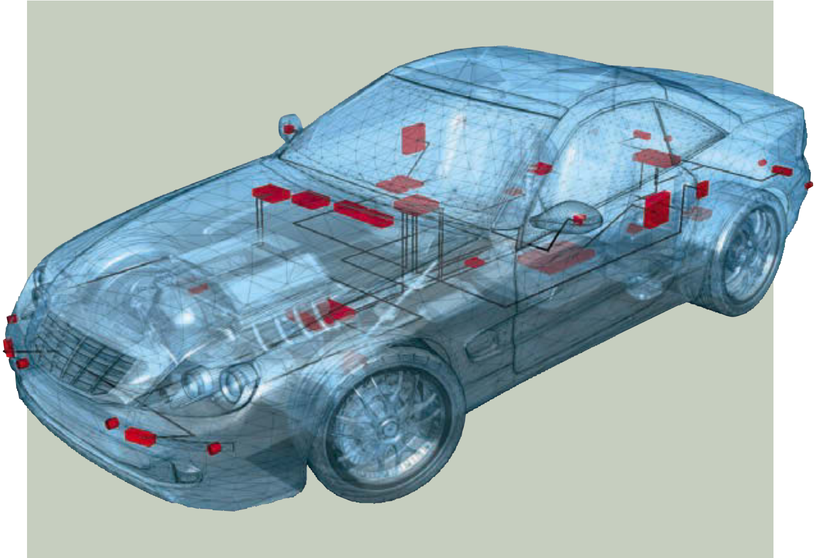
In the development of software for automotive ECUs, model-based development and automatic production code generation have become standard industrial methods all over the world. Ever since its launch in 1999, TargetLink, dSPACE's production code generator, has been a driving force in this process. Today,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

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

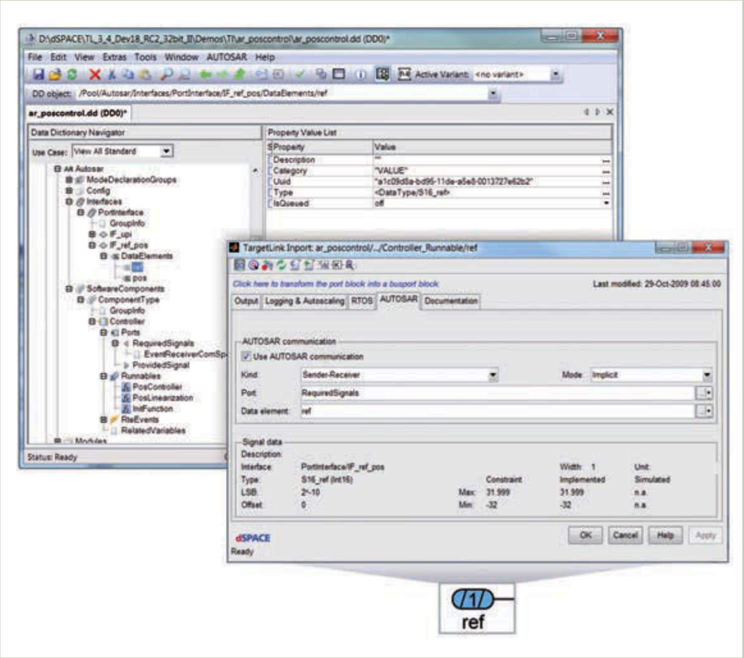
TargetLink has been specifically designed for production-quality autocoding. It can easily match the efficiency of code produced by human programmers in terms of memory consumption and execution speed – without compromising readability. The generated code can be fixed-point or floating-point, or a mixture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

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





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



D:\dSPACE\TL_3_4_Dev18_RC2_32bit_II\Demos\Tl\ar_poscontrol\ar_poscontrol.dd (DD0)*

File Edit View Extras Tools Window AUTOSAR Help

Active Variant: <no variant>

DD object: /Pool/Autosar/Interfaces/PortInterface/IF_ref_pos/DataElements/ref

ar_poscontrol.dd (DD0)*

Data Dictionary Navigator

Use Case: View All Standard

- Autosar
  - ModeDeclarationGroups
  - Config
  - Interfaces
    - PortInterface
      - GroupInfo
      - IF_upi
      - IF_ref_pos
        - DataElements
          - ref
          - pos
  - SoftwareComponents
    - ComponentType
      - GroupInfo
      - Controller
        - Ports
          - RequiredSignals
            - EventReceiverComSp
          - ProvidedSignal
        - Runnables
          - PosController
          - PosLinearization
          - InitFunction
        - RteEvents
        - RelatedVariables
- Modules

Status: Ready

Property Value List

Property	Value
Description	""
Category	"VALUE"
Uuid	"a1c09d8a-bd95-11de-a5e8-0013727e62b2"
Type	<DataType/S16_ref>
IsQueued	off

TargetLink Inport: ar_poscontrol/.../Controller_Runnable/ref

Click here to transform the port block into a busport block

Last modified: 29-Oct-2009 08:45:00

Output | Logging & Autoscaling | RTOS | AUTOSAR | Documentation

AUTOSAR communication

☑ Use AUTOSAR communication

Kind: Sender-Receiver

Mode: Implicit

Port: RequiredSignals

Data element: ref

Signal data

Description:

Interface: PortInterface/IF_ref_pos

Width: 1

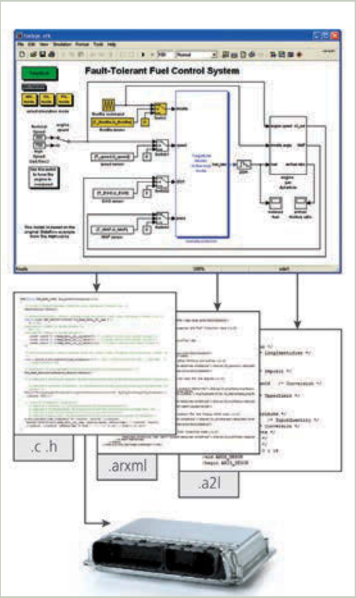
Unit:

			Constraint	Implemented	Simulated
Type:	S16_ref (Int16)				
LSB:	2^-10	Max:	31.999	31.999	n.a.
Offset:	0	Min:	-32	-32	n.a.

dSPACE

Ready

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



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

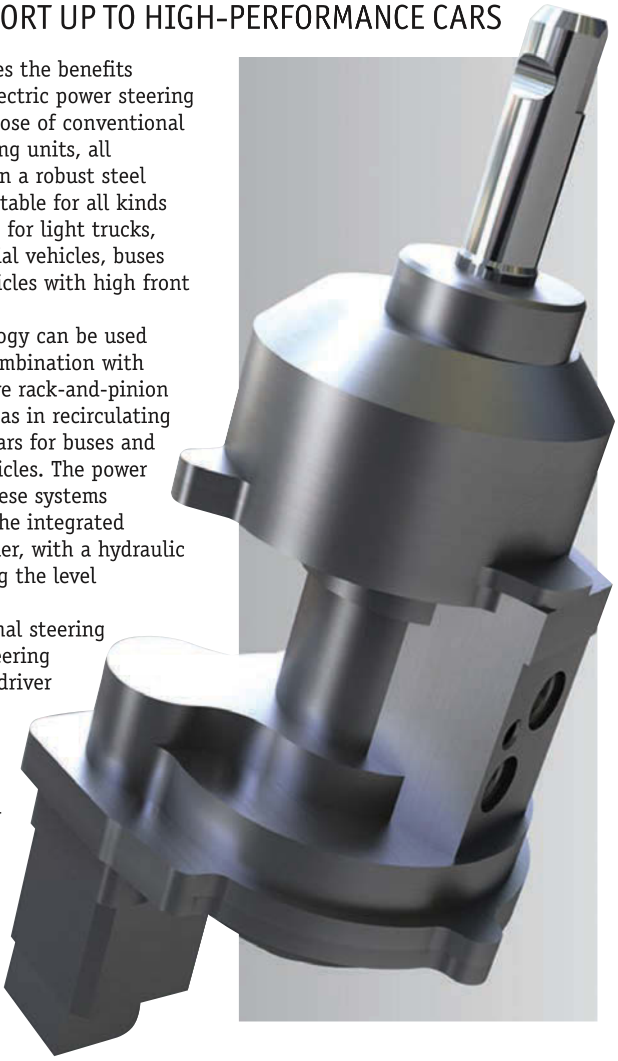
One prominent example of TargetLink's automotive focus is its native integrated Autosar support. TargetLink provides a wide range of functions for designing, autocoding and testing Autosar-compliant software components. Autosar round trips with other tools are particularly efficient thanks to the TargetLink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

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

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

Hydraulic steering assist

TEDRIVE'S INTELLIGENT HYDRAULIC STEERING ASSIST IS DELIVERING MORE SAFETY TO ALL VEHICLES, FROM PUBLIC TRANSPORT UP TO HIGH-PERFORMANCE CARS



RIGHT: **USING THE IHSA SYSTEM FROM TEDRIVE STEERING IN RACK-AND-PINION STEERING ENABLES THE IMPLEMENTATION OF ALL SAFETY AND COMFORT FUNCTIONS IN HYDRAULIC STEERING GEARS FOR PASSENGER CARS**

What do a light commercial vehicle (LCV) and a high-powered sports car have in common? At first glance, not much, but if you take a closer look you can see that they both have a similar steering system – rack-and-pinion steering gears. It is this rack-and-pinion steering system area that Tedrive Steering has innovated in, with its advanced steel housing and modular intelligent Hydraulic Steering Assist (iHSA) technology. By doing so, all safety and comfort functions are now available with hydraulic steering systems, too. Tedrive Steering is using performance-optimized, rack-and-pinion steering to pursue its objective of supporting vehicle manufacturers in the development of weight-reduced, more CO_2-efficient systems, while increasing safety and steering comfort for passengers and drivers.

In recent years, the demands on steering systems for passenger cars and LCVs have exceeded the simple functionality of steering assistance. Additional safety and comfort features, such as automatic parking, active lane-keeping, city mode and variable boost curve, which need vehicle speed signals, superimposed steering angle/torque or need-based controlled power consumption, are increasingly becoming part of engineering work. Tedrive Steering's iHSA combines the benefits familiar from electric power-steering systems with those of conventional hydraulic steering units, while retaining a robust overall steel housing design, which improves steering performance and increases steering feeling and precision.

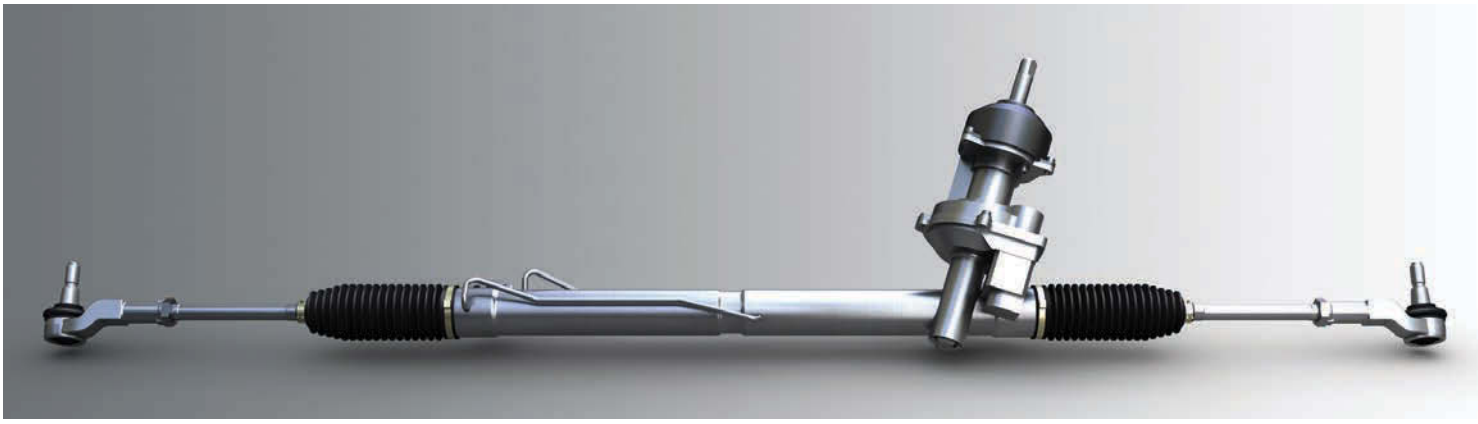
The iHSA technology, which recently won the Europe Frost & Sullivan Award for Product Leadership, enables the incorporation of driver assistance systems into hydraulic steering gears. The integration of the patented iHSA module into conventional Tedrive rack-and-pinion steering systems now makes all safety and comfort functions available to all LCV and passenger cars, whether a taxi or a high-performance car. The iHSA module combines the benefits familiar from electric power steering systems with those of conventional hydraulic steering units, all contained within a robust steel housing and suitable for all kinds of cars, but also for light trucks, heavy commercial vehicles, buses and special vehicles with high front axle loads.

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

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

Installed alongside the motor is a torque sensor that measures the driver's steering movements, providing the data necessary for system regulation. A control unit gathers all the signals and contains the algorithms required for controlling the steering. The system provides the interface to the vehicle's communication system, such as the CAN bus, and facilitates the application of hydraulic power steering in conjunction with assistance systems.

This torque overlay provided by the iHSA module means, for instance, that passenger cars and LCVs can be actively kept in the correct lane without the need for driver intervention. This has advantages for sports cars in particular, which travel at high speeds. The active lane keeping system kicks in as soon as the car veers from the lane, thus preventing often severe accidents. Furthermore, the plug-in module enables the incorporation of functions, such as automatic parking and city mode. The city mode function is a great help to



taxi drivers, who spend most of their time driving in city traffic. In city mode, the level of power steering assistance increases, making steering easier and more comfortable. As vehicle speed rises, the level of power assistance is reduced. The driver has more direct, more precise steering feedback, which is safer when driving at higher speeds.

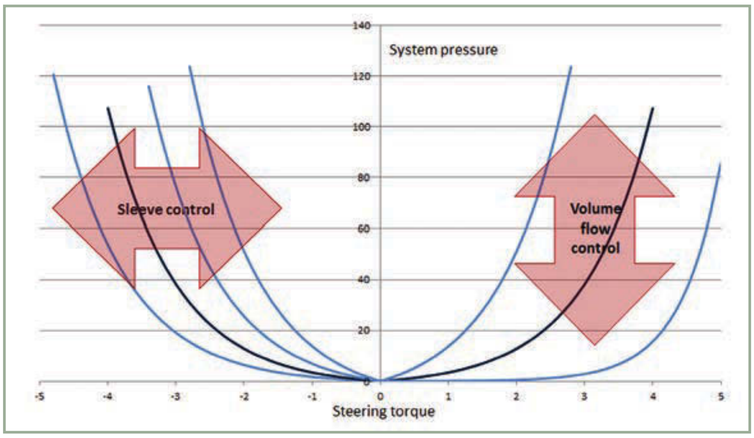
The automated park assist supported by Tedrive's technology offers a comfortable, hands-free solution that eases parking maneuvers. It is activated at the touch of a button. Sensors measure the length of the parking spot when it is slowly driven past. During the subsequent parking maneuver, the steering assistant takes over the steering input necessary to reverse into the space. The driver only has to operate the accelerator and brake pedals to complete the parking maneuver.

To guarantee functional safety, the iHSA system is developed in accordance with ISO 26262. In a comparison between iHSA steering and an EPS system, the iHSA system demonstrates a lower level of risk in terms of functional safety (ASIL B/C). This is based on the fact that the maximum applied torque overlay is mechanically limited and considerably lower than that of EPS. Depending on the torsional stiffness of the torsion bar, the maximum superimposed torque can be 4-5Nm. Thus, even in the event of a system malfunction, the driver is able to override it by steering manually.

The volume flow in the system can be adjusted if a demand-controlled hydraulic pump is used in addition to the iHSA steering. If no steering assist is required, the volume flow and thereby the power loss can be reduced. Using iHSA technology, the volume flow can also be kept low, for example at a CO_2-optimized level, even with slight steering movements.

The steel housing design enables the installation of a CO_2-saving high-pressure system. This robust steel design can withstand a pressure of >400 bar. Owing to the thinner walls and the tight-fitting welded-on pipes, the system requires only a very small installation space and is no heavier than the conventional aluminum housings in spite of the use of steel. In addition, the steering precision is noticeably improved by the more rigid steel housing. The steering system can also be used as a supporting element of the front axle.

The development of the iHSA technology considerably improves the performance parameters of hydraulic steering systems. A hydraulic steering system has been successfully converted into an active steering assist system that covers all the functions of an electromechanical steering system. In addition to improved steering functions, the benefits include optimized installation dimensions, cost and design advantages for platform strategies and CO_2-saving potential. All passenger car classes up to high-performance cars and LCVs benefit from iHSA steering regarding safety and comfort, but more importantly the OEM could make an important contribution toward improving road safety.



ABOVE: **TEDRIVE'S RACK-AND-PINION STEERING GEAR WITH A PATENTED IHSA SYSTEM**
BELOW LEFT: **THE VARIABLE BOOST CURVE CONTROL**

Future technologies

JOHN BARLAGE, DIRECTOR OF PRODUCT STRATEGY, BORGWARNER TORQTRANSFER SYSTEMS, EXPLAINS THE COMPANY'S VISION FOR POWERTRAIN ADVANCEMENT

RIGHT: **BORGWARNER'S FXD ELECTRONIC LIMITED-SLIP DIFFERENTIAL**

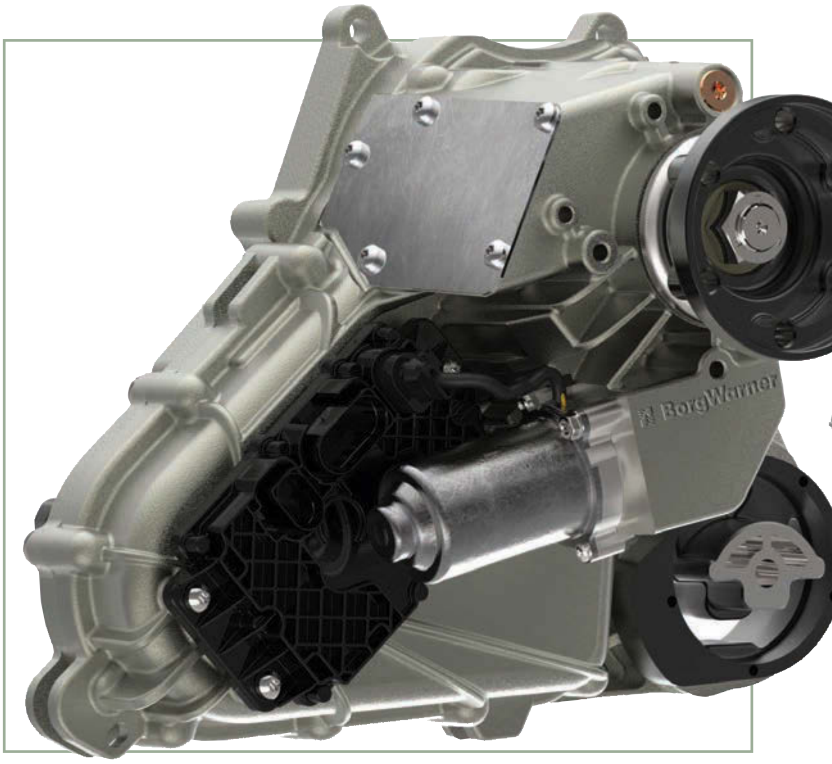
The demand for all-wheel drive (AWD) applications is not limited to the off-road vehicle or SUV segments. How important is the growing demand for vehicle dynamics solutions for the development of the sedan market?
All-wheel drive continues to be in demand across all vehicle segments, with a forecast global growth rate of 3.1% through 2019. Sedans represent the third-largest AWD segment (13%), below pick-up trucks (20%) and unibody SUVs (51%). AWD systems are recognized for delivering more than just traction, but also greatly contribute to vehicle handling, driving dynamics and active safety attributes, which are embraced by today's performance sedans.

Which AWD technology will grow in the medium and long terms?
The dominant AWD architecture continues to be active on-demand AWD, in which one axle is the primary driven axle and torque is transferred to the secondary axle on demand. This has been the case for the front-wheel drive (FWD)-based AWD segment and will continue for the long term. With respect to the rear-wheel drive (RWD) AWD segment (specifically transfer cases), part-time AWD represents 53% of the segment today, but platforms continue to add or switch to on-demand AWD. In addition, full-time AWD continues to decline as platforms switch to on-demand AWD.

OEMs adopt various strategies regarding their driveline portfolios for specific vehicle segments and strive to achieve optimized performance, dynamics, traction and comfort. How does BorgWarner support OEMs in fulfilling these objectives?
Active on-demand AWD is a key enabler to optimize vehicle dynamics due to the wider range of torque transfer authority compared with full-time AWD. Due to integration of on-demand AWD with other vehicle systems, and combined with BorgWarner's proven controls and systems integration capabilities, OEMs have realized major vehicle-level benefits from the optimization and customization of specific traction and vehicle dynamics characteristics using the same driveline system across several vehicle platforms. In addition, on-demand AWD more easily enables driveline disconnect systems for enhanced fuel economy.

How can you improve upcoming all-wheel drive systems in terms of weight reduction and fuel efficiency?
In general there are two approaches. One is to disconnect the secondary driveline in an on-demand AWD architecture to provide a highly efficient 2WD mode. The benefits of this approach depend on the actual duty cycle between 2WD and AWD modes, as well as the efficiency of the base driveline. The alternative approach is right-sizing the driveline in combination with efficiency optimization strategies such as a highly integrated on-demand rear-drive module (RDM) and optimized power-transfer unit (PTU). This can result in efficiency gains approaching that of a driveline disconnect system, but with far less complexity, mass and cost while maintaining AWD availability at all times. BorgWarner continues to develop and launch both type of systems because we continue to see a wide range of requirements depending on the OEM.

With Generation V, you provide the latest innovation in electrohydraulic clutch control. What will the next steps in development be?
BorgWarner is constantly evolving its technology to deliver reduced cost and weight while delivering outstanding performance. The key to GenV's success was the centrifugal electrohydraulic actuator, which has spread to other applications such as FXD, disconnect coupling and our pre-emptive transfer case products. We are actively developing the next generation clutch system tailored to the increasing need for vehicle dynamics performance and system integration.



ABOVE LEFT: **BORGWARNER'S PRE-EMPTIVE ON-DEMAND TRANSFER CASE**
ABOVE: **THE INTEGRATED REAR DRIVE MODULE**

Could you summarize the key advantages of BorgWarner's FXD technology and its benefits?
Our FWD electronic limited-slip differential system, known as FXD and launched in 2013, on the VW Golf GTI with Performance Pack, electronically controls the locking torque between the front wheels, directing power to the wheel with the best traction even before wheels slip or spin. When accelerating in a turn the system delivers a torque-vectoring effect, shifting more power to the outer wheel to reduce inner wheel slip and greatly reducing understeer. To enhance vehicle stability, the system can shift more power to the inner wheel, which provides a yaw-damping effect to reduce oversteer. The result is a fun-to-drive experience, providing enhanced cornering and vehicle dynamics performance. Another key advantage is the modular design, which easily adapts to the existing interface of an AWD configured transmission. BorgWarner offers other eLSD solutions for primary (RXD) and secondary (XWD) driven axles.

Can you give us more details about your next-generation transfer cases, which are more efficient and compact?
Our next-generation on-demand AWD transfer case, launching in 2015, will use pre-emptive clutch actuation to provide higher torque transfer capacity as well as higher control accuracy, for enhanced vehicle dynamics in a compact package. In addition the system provides much lower drag torque for increased efficiency and enables a highly efficient 2WD mode when part of a front-axle disconnect system. Additional functionality includes pumpless lubrication and active oil sump management for efficiency and fuel economy gains.

Fuel efficiency and hybridization benefits are both key drivers for eAWD systems. With volume and premium OEMs, the cost depends on functionality levels. Electric AWD technology is expected to grow considerably as OEMs try to meet stringent emissions standards. What is BorgWarner's approach to this technology and what do you see as the next big thing that might influence the future of drivetrain applications?
BorgWarner has developed an eAWD system that also delivers torque vectoring performance as part of a through-the-road HEV system. The challenge of hybridization is to bring a value proposition to the consumer, but the reality is that some level of hybridization will be required on most vehicles in the future for OEMs to meet fuel economy and emissions regulatory requirements. The next big thing for us is vehicle electrification beyond eAWD. We are embracing all aspects of this future state, from the impact of 48V vehicle architectures on actuator technology to alternative high-value powertrain hybridization concepts, which deliver benefits beyond regenerative braking and boosting.

Model-based engineering

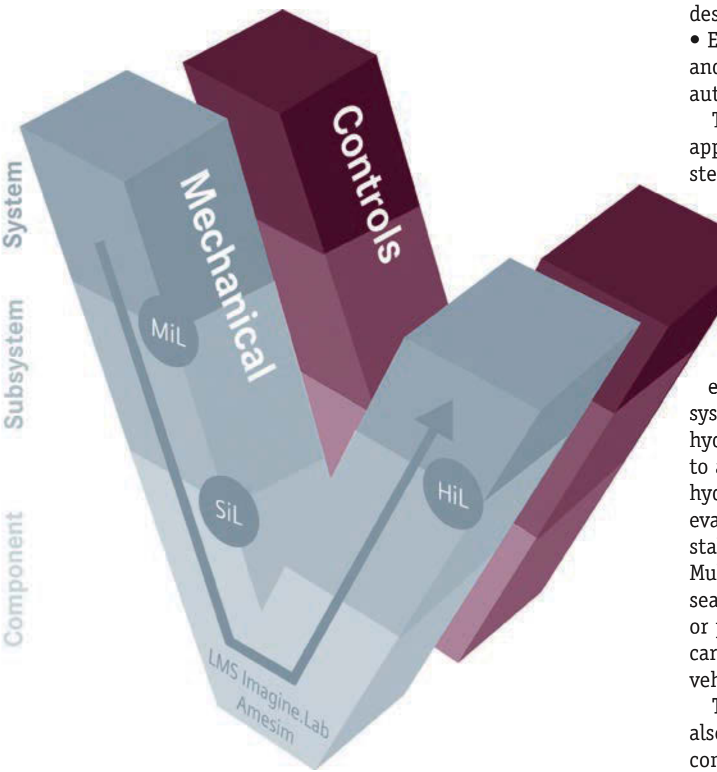
APPLYING PHYSICS IN SYSTEMS DEVELOPMENT BRINGS MANY ADVANTAGES, INCLUDING BRIDGING THE GAP BETWEEN THE SYSTEM AND CONTROLLER DESIGN PROCESS

The product race has become an innovation race, reconciling challenges of branding, performance, time-to-market and competitive pricing, while complying with ecological, safety and legislation constraints. Integrated design and engineering methods based on virtual testing are becoming standard practices in product and control design processes. They support the development of mechatronic systems and help address the challenges posed by their inherent multidisciplinarity and the integration of control system concepts. Front-loading the design engineering process requires adoption of a global simulation approach.

Engineering of mechatronic systems requires the application of two interconnected design cycles – one focusing on the multidomain system engineering, and the other focusing on control engineering.

The challenge is to apply a mechatronic system engineering approach based on scalable and interoperable simulations throughout the complete design process, including for target setting, concept systems engineering, functional simulation, and test validation.

BELOW: **DOUBLE DESIGN CYCLE INCLUDING MECHANICAL AND CONTROL ENGINEERING**



To meet the requirements of multidisciplinarity and control design, LMS Imagine.Lab Amesim from Siemens PLM Software is an open-integration platform that enables users to model and simulate vehicles in a straightforward and continuous integration process covering model-in-the-loop (MIL), software-in-the-loop (SIL), hardware-in-the-loop (HIL) and driver-in-the-loop. The solution includes physical component libraries, template models, data management tools, platform dedicated toolsets, and interfaces with simulation suites such as LMS Virtual.Lab Motion, Adams or Simulink.

The challenge of multidisciplinarity is fulfilled with the following LMS Amesim libraries:

- Mechanical libraries: 1D mechanical, 3D mechanical, powertrain or vehicle dynamics;
- Thermofluid libraries: thermal-hydraulic, pneumatic or component design;
- Electrical libraries: electric motors and drives, electromechanical or automotive electrics.

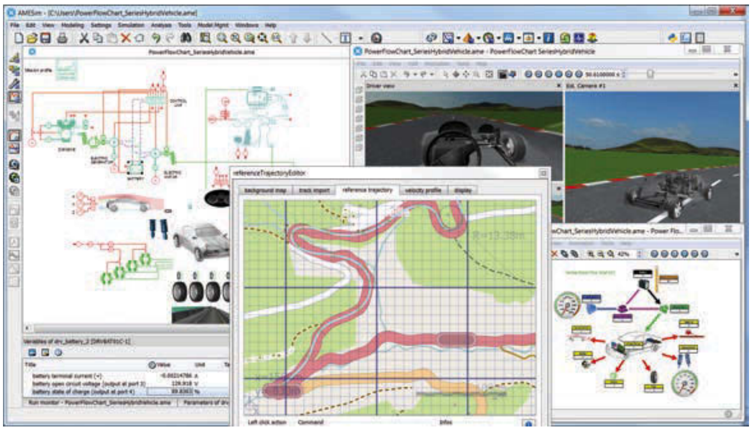
This multidisciplinarity allows applications such as braking, steering, powertrain, EVs and HEVs, vehicle dynamics and suspension components.

Designing and optimizing individual braking components such as booster, master cylinder, hydraulic modulator of an electronic stability control (ESC) system, as well as the complete hydraulic braking circuit, to assess dynamics, compare hydraulic architectures and evaluate braking distance or vehicle stability, are typical capabilities. Multidisciplinarity enables the seamless handling of hydraulic and/or pneumatic braking systems for cars, trucks, buses, off-highway vehicles and trains.

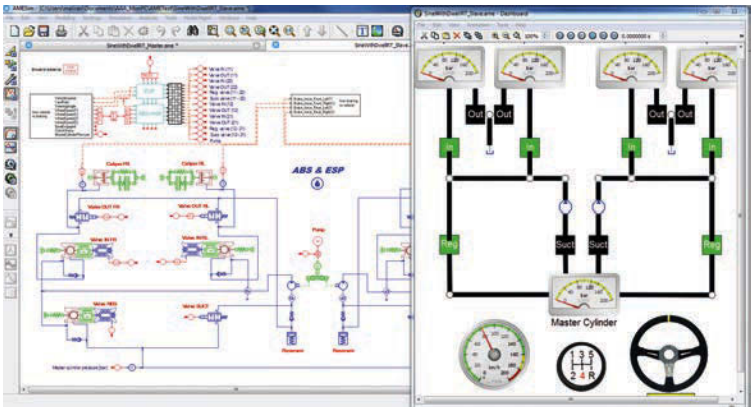
The LMS Amesim fluid libraries also support sizing and analyzing components of active anti-roll and suspension systems. Trade-offs between vehicle handling and comfort, resulting from improved damper design, air-spring systems and hydraulic or electric active roll stabilizers, can be assessed in a unique environment. Thanks to model scalability, the fluid libraries allow OEMs to carry out functional analyses and enable suppliers to perform detailed design of shock absorbers. Thermal aspects can also be explored to assess influences on air-spring systems for vehicle comfort and self-leveling.

Chassis electrification has modified active-roll systems. Electrical actuators have replaced hydraulic components. It has also changed braking systems with evolved brake pedal amplification systems, regenerative braking and electric parking brakes. However, the steering system was the first to move to electric power. The multi-domain capabilities of LMS Amesim enable users to deal with hydraulic (HPS), electrohydraulic (EHPS) and electric power-steering (EPS) systems for cars, trucks and buses. All EPS structure types (such as belt drive, worm gear, ball and nuts, direct drive, or rack assist) can be tackled mixing a mechanical functional approach and electrical devices. More in-depth vibration, coupling and stability (shimmy phenomenon) analyses in parking or normal driving conditions can be explored using the LMS Amesim vehicle model or interfaces to multibody simulation programs. The LMS Amesim optimization tool helps engineers achieve optimal steering performance by identifying critical parameters in the steering system and/or suspension geometry.

All these chassis components and systems form the chassis actuators of the system to be controlled, i.e. the vehicle itself. To meet the demand for a shorter complete vehicle development process, LMS Amesim includes a dedicated and easy-to-use environment for chassis specification, design and validation toward functional analysis and design for vehicle dynamics. With a fully embedded application-oriented graphical user interface, end users



LEFT: **ENERGY FLOW CONSUMPTION BETWEEN COMPONENTS USING REALISTIC SCENARIOS**



BELOW LEFT: **ELECTRONIC STABILITY PROGRAM (ESP) FOR A HYDRAULIC CIRCUIT**

and chassis component suppliers have access to predefined chassis functions for fast analyses. For OEMs exploring new designs in early phases and requiring more flexibility, LMS Amesim provides a second vehicle library whose main requirement is modularity. The vehicle models come with a large set of dedicated tools and workflows including data management, templates, ISO and NHTSA-predefined maneuvers. It also provides a realistic driver model based on MPC theory, OpenStreetMap road import, trajectory designer and mission builder, K&C designer, specific chassis criteria analyzer, and optimization tools.

Besides the potential for longitudinal dynamics related to LMS Amesim powertrain and IFP-Drive libraries, torque vectoring and all-wheel-drive systems are also relevant. However, this is not limited to conventional vehicles; stability problems linked to electric and hybrid transmissions are also of interest. Coupling the vehicle to aforementioned libraries allows for exploring torque-generation and stability problems due to interactions between torque vectoring or regenerative braking and the electronic stability program (ESP). For EVs, energy consumption scenarios can also be assessed. Coupling lateral dynamics and road data – coming from GPS or OpenStreetMap – enables evaluating the vehicle performance on more realistic roads. Since all LMS Amesim models are based on power exchanges, it is easy to track all energy consumption to increase vehicle energy-efficiency.

The development of active functions independently from the design of the system they are controlling can result in suboptimal designs, unexpected integration problems, and unexploited synergetic effects. Addressing the integration challenge requires a model-based systems engineering (MBSE) approach, bringing together the systems and the control design, across all phases of the design process (MIL/SIL/HIL).

The MBSE approach is based on scalable and interoperable simulations. Interoperability requires common frameworks for development and exchanges, and easy-to-use interfaces to control software such as Simulink. Integrating the system, the actuators and some of the sensors in a unique environment seamlessly coupled to the control logic is a crucial point to ensure continuity within the development process and to reduce time-to-market.

For system and control integration, model simplification techniques and continuity in modeling levels are becoming key points. As the system design process evolves, models are becoming more and more complex. However, at certain milestones, control designers require reliable physical models to run in real time. Thanks to a unique model simplification capability based on power exchanges, LMS Amesim enables system designers to simplify complex models. This technique has already been applied to a transmission, ESP hydraulic modulator and hydraulic suspension and ensured model scalability and parameter sustainability from MIL to HIL. Even the system designer can benefit from model simplification by gaining insight of the parameters governing the system behavior.

Another step in process continuity is sharing the plant model between the system design and control design departments, which requires common agreement of milestones in the process and modeling levels at these milestones. LMS Imagine.Lab Sysdm from Siemens PLM Software provides a solution for managing models coming from different environments (plant and control) as well as the corresponding parameters.

Modeling scalability, interfaces to Simulink and data management are essential features for multi-domain simulation and control engineering integration. One can identify optimal configurations between the plant model and controllers, and predict vehicle system responses to steering, braking, throttling and shifting, as well as external inputs (road, wind). Applying more physics to systems development so as to use controllers in a more reliable and accurate plant model (even in real time), and bridging the gap between system and controller design process, are critical in the design process.

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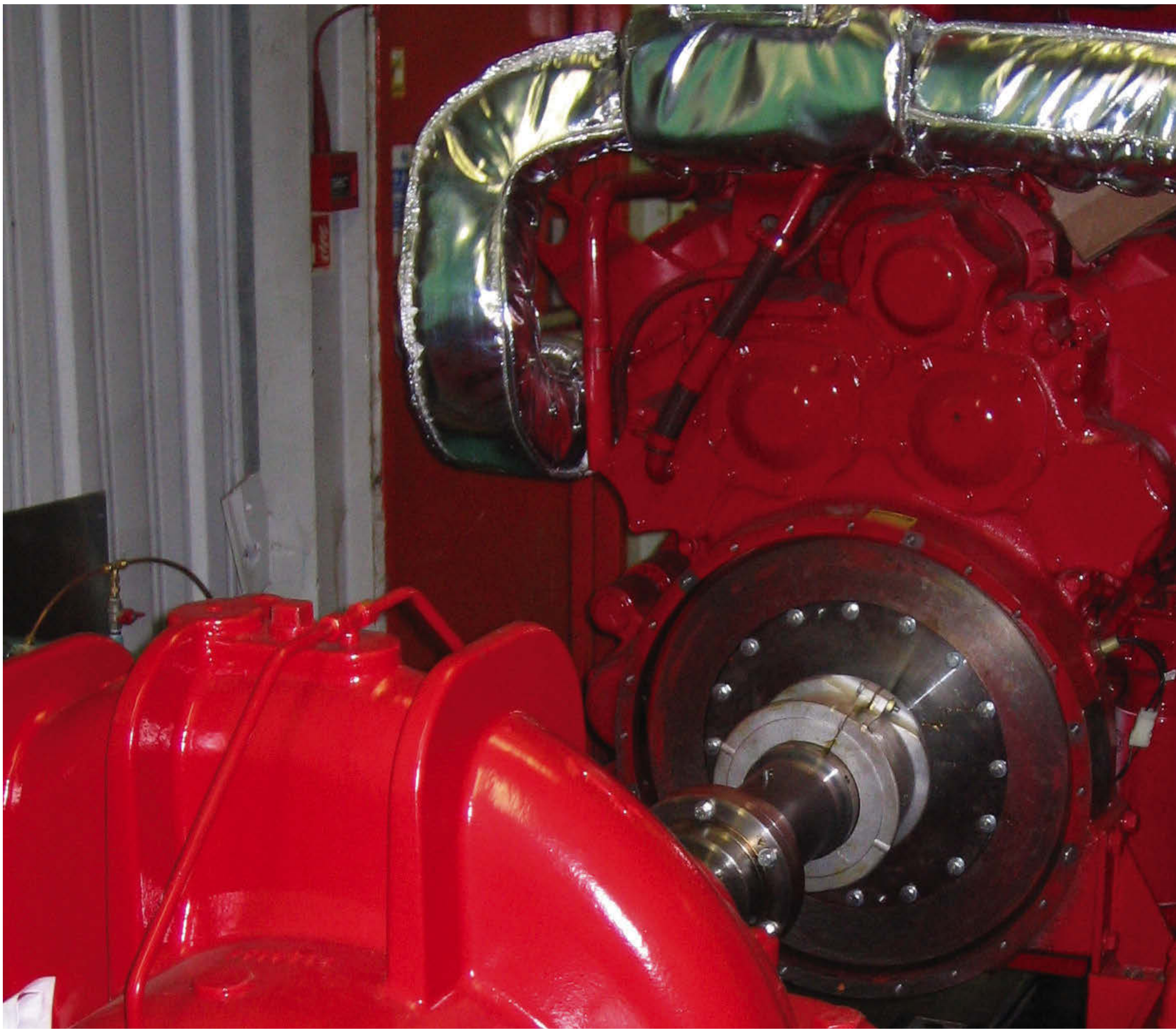
Sensor solutions

STRAINSENSE IS A PROVIDER OF INNOVATIVE SENSOR AND INSTRUMENTATION SOLUTIONS TO THE MOTOR, MOTORSPORT AND OTHER HIGH-TECH INDUSTRIES



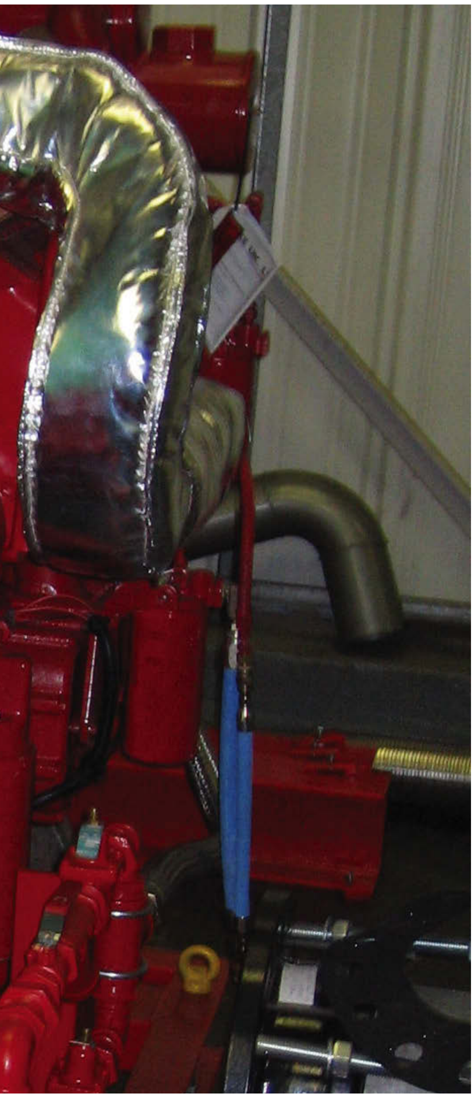
RIGHT: **TORQUE MEASUREMENT SYSTEM BETWEEN 30-LITER DIESEL ENGINE AND CENTRIFUGAL FIRE PUMP ON TEST RIG**

Much of StrainSense's work is confidential, but it does supply product and expertise to many of the major UK-based motor manufacturers and leading automotive test bodies and consultants. It also lists a good proportion of the Formula 1 grid among its customers and is equally active in MotoGP and the World and British Superbike formulas. Additionally it is involved in a number of American motor racing series and exports product to France, Italy, Germany and Japan.

StrainSense was founded 12 years ago by Anthony Cross, who has been immersed in the business of sensors for no less than 42 years. He was initially involved with weighing systems and their R&D. While subsequently engaged in the manufacture, development and selling of sensors and the running of related companies, he gained experience of a large number of industries, and StrainSense itself now operates within the rail, military, aerospace, marine, petrochemical, power, sub-sea and general industry sectors, as well as the motorsport and mainstream automotive arenas.

Cross established StrainSense to have the freedom to choose whatever products he wished in satisfying the many and varied applications encountered in the automotive world. He also sometimes designs products to meet special requirements – these tasks are usually customer led, though he does initiate items from scratch if he feels there is an untapped opening in the market.

The company focuses much of its attention on the test and measurement marketplace, and typical customers are those concerned with component or assembly testing within the R&D departments of everything from major motor manufacturers to their



individual suppliers. StrainSense also services the needs of a number of universities, many of whom are engaged in projects with the same or different car makers. The relationships this creates with the students can be beneficial in the long term too, as they are already aware of StrainSense's multifaceted capabilities by the time they begin full-time employment.

The sensor market is quite crowded, but StrainSense attributes its success to identifying a number of niche sectors, creating a range of unique products, and its extensive applications knowledge and expertise.

"Many of our monthly orders emanate from new customers. While this sounds impressive, much of the work is project-based rather than OEM supply, which means it may be a while before we hear from some of those companies again," states Cross. "Nevertheless our client base and turnover continue to increase year on year.

"Crash testing is a particular area of growth at present, and we are involved with a range of motor manufacturers and major automotive test facilities, as well as the aviation industry. We have the required standards to sell into this market and offer two core products that are especially applicable. Each supplier tends to have its own area of expertise – for example, where there are a number supplying crash test dummies, we can provide sensors for those dummies to measure force, vibration and angle. We are also involved in the testing and development of crumple zones, pedestrian crash protection, and the mounting, load and tension of seatbelts."

A typical example of how StrainSense supports one major UK-based motor manufacturer is by working with both its road load data and structural test departments in the development and refinement of individual components and assemblies. It helps the former instrument-up a vehicle with accelerometers on the wheels, linear position sensors on the suspension, sensors on the engine and gearbox mounts, torque sensors on the driveshaft, pressure sensors on the brakes, etc. This enables accurate measurement of the dynamic forces on the car in motion – the displacement of the suspension, how much of the load is absorbed by the suspension and how much is transferred to the shell, etc. This enables the building of a complete profile of the vehicle driving in a real-world scenario, which can then be recreated by the structural test department as required – say, in the testing and development of engine mounts. Once rigged-up to receive the same loads as on the road, a mount can be treated to an accelerated program over maybe a 12-month period, which would be impossible to achieve on the road. StrainSense provides all the systems and expertise required for such exercises.

Also typical are the full measurement systems created for individual functions, such as braking, where a force transducer might be fitted to the pedal together with an accelerometer and position sensor, and the discs equipped with a very rapid dynamic pressure sensor and accelerometer, A recent innovation is the equipping of the individual brake pads with force transducers. Together these fitments provide a full validation of the system that could, for example, facilitate improvements to the feedback of the ABS system to prevent internal juddering of the vehicle, etc.

The company also assists with problem solving, an example of which was the discovery that a vehicle chassis was twisting sufficiently under extreme load to tighten the rear seatbelts. StrainSense fitted load cells to the belts concerned so that tests could be conducted with a manikin in place and accurate data obtained. New products are continually under development and, having enjoyed considerable success with its linear position sensors in motorsport and other arenas, StrainSense is now in the process of launching a range of very small, high-temperature rotary sensors for the same markets.

StrainSense is headquartered just north of Milton Keynes, UK, in the heart of what's known as Motorsport Valley, nine miles from reigning World Constructors' champion Infiniti Red Bull Racing and a maximum of 70 from the other seven UK-based F1 teams. Major vehicle manufacturers like Jaguar Land Rover Automotive and such key industry test facilities as Millbrook and MIRA are equally close at hand.

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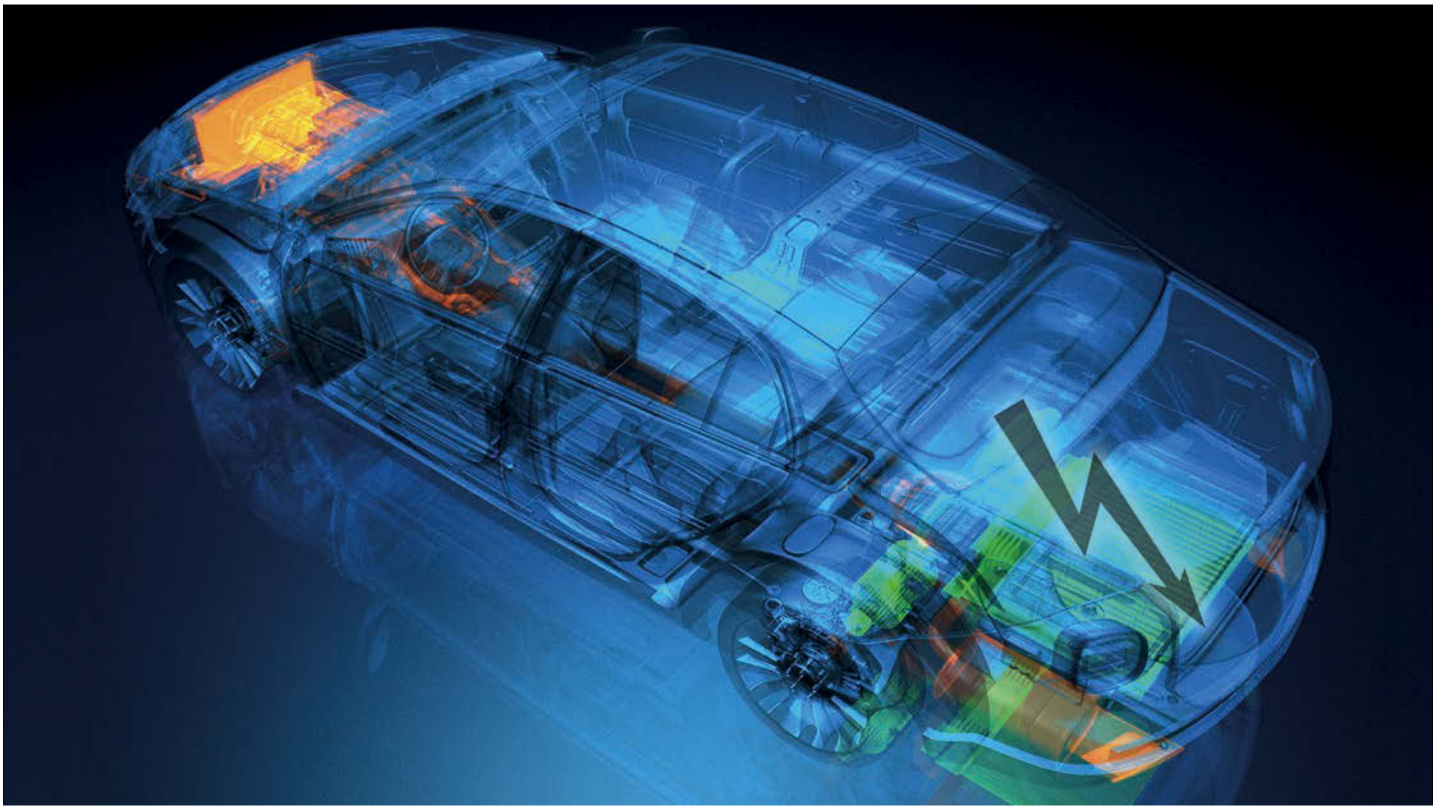
Virtual development

IPG'S CARMAKER SOFTWARE IS MAKING THE DEVELOPMENT AND TESTING OF FUTURE ELECTRIC AND HYBRID VEHICLES POSSIBLE TODAY



ABOVE: **VARIOUS POWERTRAIN CONCEPTS CAN BE SET UP AND VALIDATED USING THE CARMAKER TEST PLATFORM SOFTWARE**

So far, none of the alternative vehicle powertrain technologies currently available have achieved a real breakthrough, in spite of the variety of concepts and the growing number of models on the market.

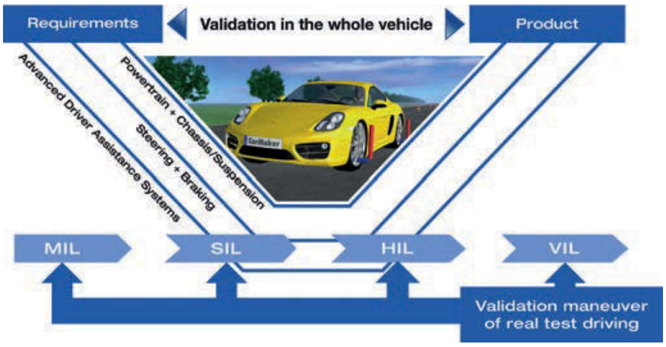
But governments around the world are committed to promoting market penetration of ultra-low emission vehicles (ULEVs) in their efforts to reduce carbon dioxide emissions. Incentivizing the purchase of such vehicles through grants and tax breaks, driving research and development through public funding, and investing in the required charging infrastructure are just some examples of actions that governments have already taken or are considering.

These actions, along with the technological progress, particularly with respect to extending the range of these vehicles, have begun to bear fruit. The sales figures of hybrid-electric and fully electric vehicles are reflecting slow but steady growth, and demand can be expected to keep rising. The development of ULEVs, however, is very complex because there has been a massive increase in the possible combinations of various electrified powertrains. The challenge lies in effectively integrating the development of the powertrain and chassis to meet specifications while keeping an eye on time and costs. Virtual test driving can support these efforts considerably.

Chassis engineers are challenged to manage a multitude of variants resulting from the use of electric motors and to make optimum choices for new vehicle designs. The increased interaction of powertrain and brakes adds further complexity. The interfaces in a full-electric or hybrid electric car are more diverse than in conventional vehicles, and a larger number of combinations and interactions must be considered. The possibility of using electric instead of purely hydraulic power for braking raises a whole host of issues that also have to be taken into account in development.

In addition, there are new ways to spontaneously distribute torque to the individual wheels. This torque-vectoring approach means the powertrain can be used to generate additional steering effects and highly influences a vehicle's dynamics. Such a system can lead to completely new issues being raised in the vehicle development process compared with those of a conventional vehicle development program. Furthermore, using a wheel hub motor opens the possibility to leave traditional development paths.

As a result of the growing complexity and increasing integration of components, it is important to run functional tests, validate electronic control units, and evaluate vehicle dynamics as early in the development process as possible. Recuperative braking has to be evaluated and tested in accordance with existing safety systems, as well as with new driver-assistance systems. Such tests can be achieved by using a simulation environment



ABOVE LEFT: **THE 'V' PROCESS OF VIRTUAL VALIDATION**
ABOVE: **CARMAKER CAN FORM PART OF A DEVELOPMENT JIGSAW WITH OTHER SOFTWARE SYSTEMS**

that also takes into account the unique challenges to be mastered in testing and validating hybrid-electric and fully electric vehicles.

The composition of powertrains in hybrid-electric vehicles may vary greatly due to the possible combinations of different types of electric motors and their positions in the vehicle. The number of electric motors to be used, the resulting weight, and the influence on vehicle dynamics raise questions. Engineers wish to take an integrated look at vehicle dynamics and road performance, which can be achieved through virtual test driving.

The possibility of different departments working on the same virtual prototypes simultaneously during the relevant development stage is one advantage offered by this approach. In the CarMaker open integration and test platform software package, various hybrid concepts can be set up and investigated. Users can integrate their own models and data records modeled from other tools, for example by means of the Functional Mock-up Interface (FMI). Furthermore, virtual test driving can be consistently used across the entire development process via model (MIL), software (SIL), hardware (HIL) or vehicle-in-the-loop (VIL) methods.

Previously created driving maneuvers and defined criteria can be used again throughout the V-process. In a customer project, for example, a hybrid sports car was set up as a concept car, using the advantage of close collaboration on only one simulation platform for system development, software development and calibration. The real vehicle prototype was built based on the simulation results that pointed out the best fitting concept to meet the development targets. Finally, a detailed vehicle model was validated based on a catalog of maneuvers, with various test runs used to optimize longitudinal and lateral dynamics, as well as the energy consumption of the vehicle.

Another occasion in which CarMaker was used for testing the control of fully electric vehicles with multiple electric motors was the E-VECTOORC (Electric-Vehicle Control of Individual Wheel Torque for On- and Off-Road Conditions) project, which was funded by the European Union within the Seventh Framework Program (FP7). The aim of this three-year project, which was coordinated by Dr Aldo Sorniotti from the University of Surrey in the UK, and completed on August 31, 2014, was to evaluate the potential benefits of individual motor control in terms of energy efficiency, safety, comfort and being fun to drive – on and off road. The design activity was carried out using vehicle dynamics simulations in CarMaker, and HIL testing of vehicle components and subsystems, which was complemented by full-scale testing of the entire system through a highly versatile vehicle demonstrator that can represent drivetrain architectures with one, two, three or four electric motors.

The integration of virtual hybrid-electric and fully electric vehicle prototypes makes the complex powertrain development work easier for engineers. The open integration and test platform enables users to investigate the advantages and disadvantages of concepts, and to find concepts suitable for meeting the requirements specified at the beginning of a development process. As a result, it is possible not only to define the engineering design of a powertrain, but also to run early hardware-independent tests of its individual components and their interaction, allowing development engineers to integrate a powertrain with a high level of maturity into the full vehicle context at an early stage.

In view of the diversity of factors to be investigated, hybrid-electric and fully electric vehicles will be keeping research and development teams busy in the coming years. Key words in this context include 'vehicle dynamics', 'ride comfort', 'thermal management', 'energy efficiency', and 'real-world fuel consumption'. Virtual test driving can also be used early to support investigations into the effects of advanced driver assistance systems. The complexity and interaction of subsystems in this context will continue to grow as more advanced driver assistance systems make their way into vehicles. Consequently, comprehensive investigations into how these systems interact will continue to increase testing requirements and make virtual test driving, as a complement to real road tests, an efficient tool in the development process.

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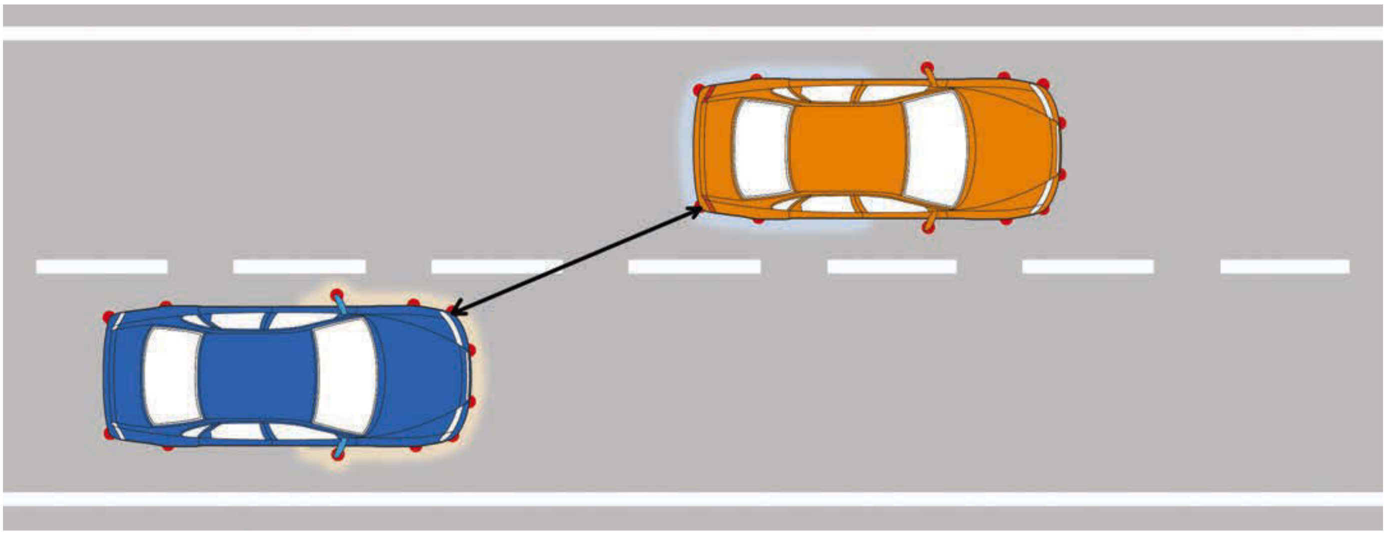
ADAS testing

THE LATEST ADDITIONS TO RACELOGIC'S VIDEO VBOX DATALOGGING SYSTEM ARE ENABLING THE NEXT GENERATION OF ADAS TECHNOLOGIES TO BE DEVELOPED



Autonomous driving is a popular topic at the moment, with various manufacturers announcing that they are confident that their cars will be doing the driving for us within a surprisingly short time. Some predictions give 2020 as the year by which the technology and infrastructure will be in place to make autonomous cars a reality.

Whether or not this timeframe is feasible, there is no denying that leaps in technology will ultimately deliver personal transport in which every vehicle occupant is a passenger. It could be argued that autonomous driving is already here, as cars can now park and brake independently. Tesla recently demonstrated an auto-pilot feature that controls vehicle speed based on traffic sign recognition; Volvo assures us that in 5-10 years its commercial vehicles will constantly scan every pedestrian, cyclist and item of roadside furniture within the vicinity of it trucks, then act upon what they see.

The combination of radar, lidar, GPS and vision will ensure that current methods of advanced driver assistance will eventually morph into these technologies becoming the actual driver of the vehicle.

Developing, then testing and finally validating these systems, has given rise to an automotive testing market that has seen dramatic upheaval in the past decade. A good example comes from Racelogic and its range of VBOX GPS dataloggers: while maintaining a core competency in vehicle dynamics testing, recent years have seen major development in the company's test and validation solutions for ADAS. A recent update to the company's range-topping VBOX 3i SL-RTK introduces some interesting features.

Traffic sign recognition systems will soon be greatly improved thanks to a new generation of high-definition cameras with better range than the current VGA resolution units. These new systems need to be tested for this greater range and for a higher number of potential recognition markers, so the VBOX Multiple Static Points application enables up to 100 such targets to be surveyed, creating a GPS map of their locations.

The desired minimum and maximum detection angles and distances for these targets are then set, and the vehicle driven along the route. When the points fall within the detection zone, the range, angle and time-to-collision parameters of up to five of the points are simultaneously displayed and logged, with any targets further away being tracked as the closer ones are passed. The GPS data is then compared with the actual performance of the system under test.

A large proportion of ADAS testing requires accurate distance and time-to-collision measurement between a subject and the target vehicle. This is usually achieved by capturing the distance between the antennas plus offsets to the edges of the vehicle body. Now, however, it is possible to 'map' the shape of the car by surveying up to 24 points around the chassis, using a ground plane antenna and survey pole. This system produces an accurate polygonal shape of the vehicle, and as the test takes place, the nearest point between the target and subject is recorded, taking account of body angle and slip as they move through corners, and enabling vehicles to pass each other in a realistic fashion.

Multiple contact points increase accuracy and shorten test times when validating blind spot and rear cross-path detection, autonomous emergency braking, adaptive cruise control, and forward collision warning systems. When developing a park-assist system, the points surveyed along one side of the car in respect of the line against which it is parking mean that a closer representation of the movement of the vehicle is captured, compared with a single-point system.

THE SYSTEM ENABLES USERS TO MODEL VEHICLES PASSING AND RE-PASSING EACH OTHER IN A REALISTIC, REAL-WORLD FASHION

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High-quality bearings

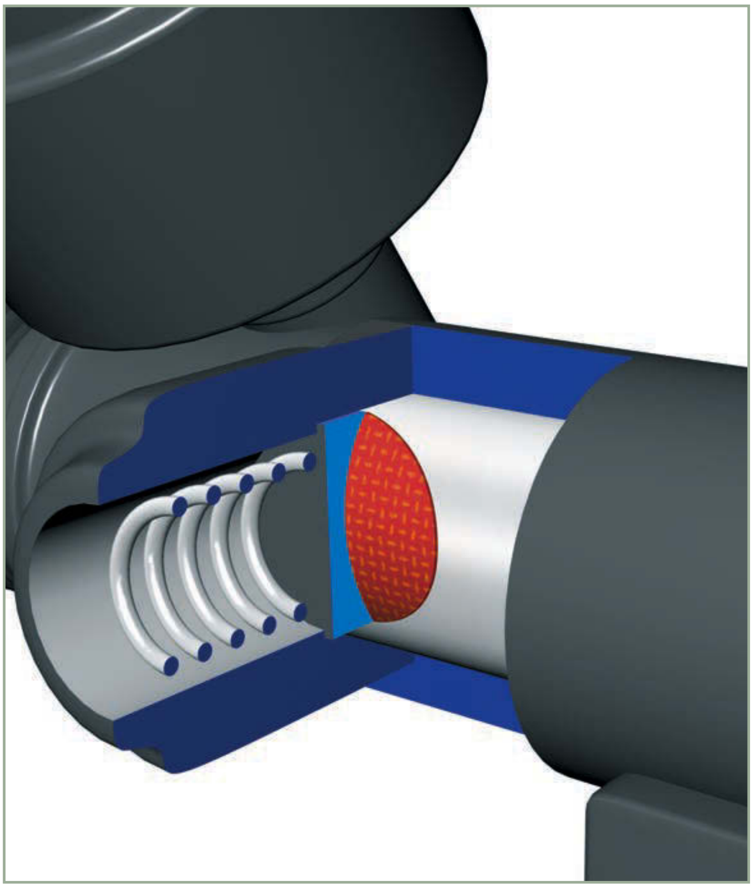
SAINT GOBAIN EXPLAINS HOW BEARINGS – SOME OF THE SMALLEST COMPONENTS IN A CAR – CAN AFFECT THE OVERALL DRIVING EXPERIENCE

A vehicle's quality is equal to the sum of its parts, even those so small that consumers may not be aware of them. Such is the case with bearings, tiny but necessary components in automotive design that are used in a range of applications throughout the vehicle, from the powertrain to the cockpit. The right component, wherever it is used, can make a big difference to performance, helping to ensure a smooth, comfortable ride – the trademark of any high-quality vehicle – and bearings are no exception. This smoothness of ride is dependent on automotive manufacturers and suppliers selecting the correct bearing solution for their application and technology.

Bearings are used in seat mechanisms, enabling them to be adjusted for comfort. With a self-lubricating polytetrafluoroethylene (PTFE) liner, composite bearings offer consistent friction control for the mechanism's long life, with no need to replenish oil or grease. They can be fitted with different lightweight and/or high-strength materials, resulting in a slimmer, lighter component that contributes to both the smart design of the vehicle and overall weight reduction efforts. Manufacturers can also install such bearings quickly, thanks to the split-ring design, which means they can be compressed into place with no adhesives or extra tools required.

Composite bearings can be adapted when customization is needed. Those designed with a PTFE liner absorb excess vibration in the mechanism, eliminating rattling, for a noise-free driving experience at higher speeds and when encountering adverse road conditions. The PTFE liner also compensates for the manufacturing tolerances of the mating components, ensuring quality mechanism performance.

At the interface between the steering rack and the steering column sits the steering yoke. This component requires a bearing to ensure smooth movement of the steering rack for quick, responsive handling of the car. When used in the steering yoke, composite bearings offer consistent low friction, thereby enhancing steering response and feel for the motorist. The PTFE liner, in combination with the yoke contact pattern, enables the rack-shaft load to be spread over the widest possible area, allowing for consistent steering feel over the system's long life.



RIGHT: **SAINT GOBAIN'S HIGH-PERFORMANCE STEERING YOKE BEARING IN SITU**

In doors, bearings sit between the hinge pin and housing to ensure smooth movement when the door is opened and closed. They also play an important role in the assembly process, when the hinge must hold the door open while the car body is painted. Automotive manufacturers have specific torque requirements on the production line to ensure that doors do not close while the car is painted. The PTFE composite bearings are sizable enough to ensure a sufficient torque level to hold the door ajar. In addition, the conductive properties of composite bearings enable the use of an electrostatic painting process on the automotive manufacturer's line. In this instance, the composite bearing allows the transfer of electricity through the hinge during the painting process so that the door can be properly painted.

Bearings are a vital component in automobiles, and they can boost both comfort and consumers' perception of quality. Though a small component, the bearing must be capable of withstanding projected stresses. It must interact well with other materials in the application, and be able to tolerate exposure to external conditions. These bearings must undergo rigorous testing to ensure that they enhance the performance of the mechanism and of the vehicle as a whole.

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Making Things Right
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High-temperature testing

WALTER+BAI'S EXTENSIVE PORTFOLIO OF SPECIALIST TEST MACHINERY ENSURES THAT THE RIGHT EQUIPMENT IS AVAILABLE FOR ANY APPLICATION

Demand for innovative materials is increasing across many sectors of industry and technology. In the fields of automotive, aerospace, energy and others, new high-temperature materials are required in order to increase efficiency, or to simply extend the life of components within the system.

Walter+Bai Testing Machines offers high-temperature material test systems for research and development, as well as for quality control applications to test steels, alloys, ceramics, composites, titanium, aluminum, graphite and many other materials.

Walter+Bai's mechanical testing solutions are offered for elevated temperature tensile, compression and flexural testing; stress rupture testing; creep-strain testing; low cycle fatigue; thermomechanical fatigue; fracture toughness and fatigue crack growth; and high-temperature, high cycle fatigue testing. Common heating methods, whether for air, vacuum or inert gases, include resistance heating, induction heating and infrared heating.

The company's modular high-temperature vacuum systems are available for temperatures up to 1,200°C, 1,800°C or 2,300°C and vacuum levels up to 10^{-6} Torr. Depending on the temperature range, and the material that is to be tested, the high-temperature vacuum systems can be supplied with wolfram, molybdenum or graphite heaters, or with integrated inductive or infrared radiant heating systems, to ensure the system is correct for the application.

In all of Walter+Bai's products, accurate strain measurement or control is provided using contacting or non-contacting laser extensometers, with an operating temperature of up to 2,300°C.

The company's high-temperature vacuum systems are compatible with the electromechanical central spindle load frames series (LFMZ), and they can be integrated into the servohydraulic LFV series.

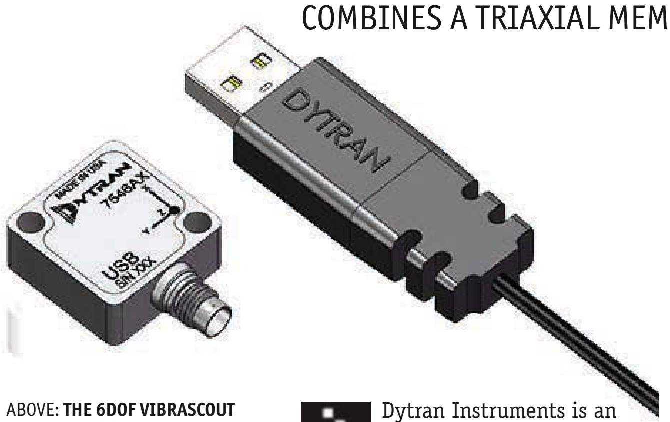
Walter+Bai supplies a wide range of material testing machines and inspection systems for the safety and quality of materials, industrial products and buildings.

Mechanical testing is carried out in many industrial sectors, such as automotive and aircraft, metal, plastic, rubber, chemical, construction and biomechanics industries, as well as institutes and universities. By serving these industries for more than 40 years, Walter+Bai has amassed extensive experience in producing material testing systems and equipment to meet a wide range of applications.

The company's engineering capabilities also mean that, in addition to its standard testing machines, it can offer customized solutions and installations for any physical testing laboratory worldwide. To ensure its customers obtain the maximum return on their investment, Walter+Bai's accredited calibration laboratory strives to offer excellent after-sales service and verification facilities, which are available for any installation, whatever the customer's specification or demand.

Vibration analysis

DYTRAN'S NEXT-GENERATION VIBRASCOUT PORTABLE DATA ACQUISITION SYSTEM COMBINES A TRIAXIAL MEMS ACCELEROMETER, A GYROSCOPE AND MORE



ABOVE: **THE 6DOF VIBRASCOUT 5346A UNIT IS AVAILABLE IN RANGES OF 14*G* AND 200*G***

Dytran Instruments is an industry-leading designer and manufacturer of piezoelectric and DC MEMS sensors to support a variety of automotive testing applications, including noise, vibration and harshness (NVH); component durability; modal and structural analysis; squeak and rattle evaluation; road load data acquisition; transmission, powertrain and exhaust manifold testing; ride quality and durability; whole-body and hand-arm vibration measurements; and other vehicle dynamics.

Since its founding in 1980, Dytran has engaged in the successful design and manufacture of piezoelectric sensing technologies, including dynamic accelerometers, pressure transducers and force sensors, to support a variety of demanding customer applications and program requirements. In response to a growing number of customer requests for expanded customer offerings to support low-frequency vibration applications, Dytran is continuously updating its sensor portfolio to include new ranges of DC MEMS single and triaxial accelerometer models.

Included among the new DC MEMS sensors now available from Dytran are the next-generation VibraScout 3D and 6D accelerometers. The VibraScout 3D and 6D plug directly into a laptop or PC for instant acquisition of triaxial or six degrees of freedom (6DOF) data; no external power supply or signal conditioning is required. This system represents a very easy and convenient way to complete three-axis and six-axis vibration studies, and to produce data for reports – all on the user's own computer.

The VibraScout is an innovative solution for fast, portable and cost-effective vibration surveys and data acquisition in a myriad of automotive testing applications, including ride quality, component testing, impact testing and end-of-line testing. Units are offered as either the 3D (5340B series, triaxial), or 6D (5346A series, 6DOF). The VibraScout 3D is available in ranges of 16*g* and 200*g*, while the VibraScout 6D is available in ranges of 14*g* and 200*g*. Both accelerometer models contain a variable capacitance (VC) MEMS chip with USB interface. Sensors are hermetically sealed in a titanium housing weighing 13g, allowing them to be used in harsh environments from test tracks to field monitoring. The frequency range of the VibraScout is 0Hz (DC) to 1,100Hz and the gyroscope is 0Hz to 250Hz (6D only). Units can withstand 10,000*g* shock.

The VibraScout vibration measurement system includes either the 7543B triaxial DC response sensor (3D) or the 7546A 6DOF DC response sensor (6D); the 6330A 15ft four-pin to USB cable assembly; and a software toolkit. The accelerometer model features power from a PC bus, and as a result no additional external power supply is required. The software package supplied with each system allows for real-time, three-directional vibration data acquisition (acceleration), three-directional orientation data acquisition (rotational; 6D only), and real-time temperature monitoring. The system stores acceleration, gyro (6D only) and temperature information, and the built-in firmware handles USB communication and provides a number of unique features including storage of device serial number and storage of accelerometer, gyro (6D only) and temperature calibration data.

Features of the VibraScout 6D post-processing software include: real-time display of acceleration, gyro and temperature data with five seconds of buffer; three-channel, multichannel, scope (rotating machinery) and real-time waterfall plots available at runtime; minimum, maximum and instant measurement values displayed for all nine channels at runtime; user-selectable frequency settings for windowing and frequency range settings; imperial or standard engineering units for all channels (unit conversion is selectable by user); embedded post processor for data export to ASCII, UFF58, Matlab compatible .MAT and JPEG files; plot overlays for channel-to-channel comparison; and many more.

An application programming interface (API) is available for customers who would like to build custom applications for the VibraScout 3D and 6D. The API provides support for any .NET-compatible client applications. Custom application development is also available.

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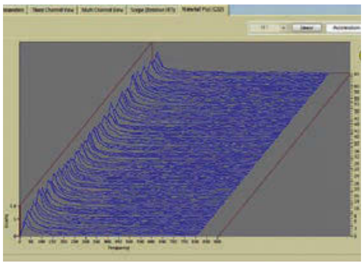
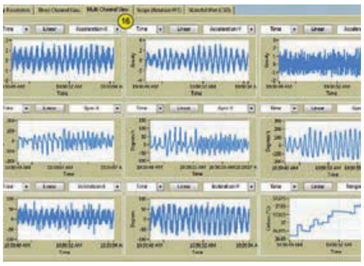
RIGHT: **THE HOMESCREEN FOR THE VIBRASCOUT OPERATING SOFTWARE**
MIDDLE: **A WATERFALL PLOT CREATED BY THE VIBRASCOUT**
FAR RIGHT: **SCREENSHOT SHOWING MULTICHANNEL ANALYSIS USING A 5346A UNIT**

Sensor drivers require Microsoft .NET Framework 4.5 to operate properly. Please install this software tool before proceeding with the rest of the installation.





Autonomous braking

DEWETRON HAS HELPED DEVELOP A COMPLETE SOLUTION FOR TESTING AUTONOMOUS EMERGENCY BRAKE SYSTEMS

RIGHT: **DEWETRON'S COMPLETE IN-CAR MEASUREMENT SOLUTION**
BELOW: **PROVING GROUND TESTING OF DEWETRON'S SYSTEM**
BOTTOM: **THE DEWE2 A4, COMPLETE WITH BATTERY OPTION AND AEB APPLICATION**

Vehicle manufacturers are continuously developing advanced driver assistance systems, such as the autonomous emergency brake (AEB). These systems have to be rigorously tested before they can hit the market. The challenges for these tests are reproducible test scenarios and the absolute synchronous acquisition of positions and movements of several cars to other important measurement data. Dewetron, a specialist in data acquisition systems, has met this challenging task with some strong partners and provides a turnkey solution.

Dewetron is teaming up with other experts in the automotive testing world: GeneSys Elektronik, a specialist in gyroscopic and GPS based sensors; Stähle, a manufacturer of high-end robotic systems; and the faculty of transportation science and technology at Dresden University of Technology in Germany, an experienced insider in vehicle testing.

The new DEWE2 data acquisition instruments from Dewetron are well suited for the evaluation of AEB systems and for any driver assistance system in general.

Trion modules are available for signal conditioning, digital I/O and bus interfaces such as CAN, and can easily be exchanged by the user. This flexibility enables users to reconfigure their system in terms of channel count by simply adding modules to the system, and in terms of functionality by plugging modules with different functionality (e.g. adding FlexRay). For very complex testing, the DEWE2 hardware is provided with an 'open system' driver so it can be used in third-party software such as DASYLab, LabVIEW or DIAdem.

One challenge is the reliable power supply of the DAQ system as well as the sensors. The DEWE2 series features an internal buffer battery that bridges power outages for up to five minutes. Internal or external battery packs allow for virtually endless supply by using hot-swappable batteries completely independent from the vehicle power grid.

The ability to acquire input signals from all sources synchronized is essential for the accuracy and the comparability of the data. The online synchronization and visualization of data from different vehicles allow calculating relative values such as distance, velocity and heading between multiple vehicles undergoing measurement.

In case of AEB testing, the DEWE2 uses the internal GPS receiver of the GeneSys ADMA as a time source for the synchronization. A sophisticated and well-proven Kalman filter combines the best of both worlds – the stability of GPS with the accuracy of high-end gyroscopes and acceleration sensors, to measure the motion of a vehicle in all three axes. Additionally, the ADMA is the sensor for all channels necessary to calculate relative position, altitude, speed and heading. This information is also used as input for control loops of actuators such as the driving robots from Stähle.

Stähle robot systems complete the solution in order to provide a full testing package for AEB. They are very quick to install compared with other robot systems and offer excellent build quality and performance. The steering robot is mounted on the standard steering wheel – so the built-in airbag is also working!

Using this complete testing solution is a huge benefit for the user, who can focus on their measurement task instead of having to deal with compatibility issues.

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Mazda MX-5

FOLLOWING THE RECENT UNVEILING OF THE ALL-NEW MX-5, *VDI* LOOKS BACK AT THE TWO-SEATER SPORTS CAR THAT BECAME AN INSTANT CLASSIC

BY JOHN O'BRIEN

The Mazda Experimental project 5, or MX-5 for short, was the Japanese brand's attempt at creating the sort of simple, yet deeply involving, sports car that was once the hallmark of British automotive manufacturers.

Conceived by Mazda's southern California design team, the MX-5 pioneered the design philosophy of *jinba ittai* (horse and rider as one). The initial planning saw the US design team favoring a front-engined, rear-drive layout akin to classic British sports cars, but their Japanese counterparts were pushing for a mid-engined, rear-driven concept.

It was only when the design process reached the clay-model stage that the MX-5 as we know it – code-named Duo 101 at the time – was decided on.

Unveiled at the 1989 Chicago Motor Show, the first-generation model, production code NA, was launched into a market where it had no immediate rivals other than the aging Alfa Romeo Spider.

The car featured an all-steel body, with a lightweight aluminum hood. The car was compact too, measuring 3,970mm long and just 1,235mm high. The car had a small frontal area, aided by the use of pop-up headlights, which helped the overall design to achieve a drag coefficient of just 0.38cd. Despite the 1.6-liter engine delivering just 115bhp, it was specifically designed for the MX-5 and featured a lightened crankshaft and flywheel, and an aluminum sump to help keep weight to a minimum. This light weight, in combination with the engine being placed behind the front axle, all helped the car achieve a near-perfect 50:50 weight distribution.

The car, in Mazda's pursuit for simplicity, was modestly specified from the factory. Steel wheels, 185/60 R14 tires, unassisted steering, and the absence of extravagances such as a stereo, air-conditioning and electric windows all helped the car achieve a curb weight of just 980kg.

Despite its Spartan interior, the nostalgic, lightweight, two-seater proved to be an instant hit with the general public, with demand outstripping supply.

This demand was further fueled by the instant universal praise the car received from journalists, due to its dynamic prowess. Featuring independent double-wishbone suspension and ventilated disc brakes all round, as well as Mazda's Powerplant Frame (PPF), which links the engine and differential with a solid connection, the MX-5 didn't just capture the ideology of classic British sports cars, but the driving experience as well.

In total over 400,000 units of the first generation were sold between 1989 and 1997.

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LMS solutions for driving dynamics

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LMS driving dynamics solutions offer an integrated approach to chassis and suspension engineering – one where vehicle handling, durability and NVH are optimized in parallel.

Thanks to the uniqueness of the LMS real-time simulation technologies using the exact same high-fidelity model able to maintain the complexity of the suspensions and subsystems (steering, brake, shock-absorber, etc.), LMS solutions support engineers in the development of design and validation of the complete real-time vehicle models chain, starting with model-in-the-loop, then moving to software-in-the-loop, up to hardware-in-the-loop.

We can guide you in all steps of the process of vehicle design, including preprogram benchmarking, target setting, concept development, detailed chassis development and prototype refinement of suspensions and steering system characteristics as well as controls integration.

For more information, please visit **siemens.com/plm/lms**

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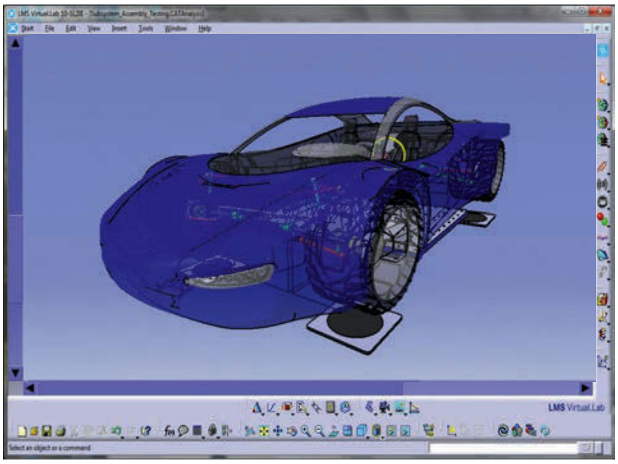

Using LMS Imagine.Lab Amesim and LMS Virtual.Lab Motion, engineers can quickly and accurately model and simulate vehicle dynamic behavior in real-time.

Answers for industry.