proActive
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Lotus Omnivore research engine unveiled

Q&A with Dr. Pawan Goenka – president of Mahindra Group's automotive unit

Welcome

I write this issue's introduction ahead of the ruling on the latest Formula 1 furore surrounding rear diffusers. As you read this, the legality of those used by some teams will have already been announced. Whatever the outcome, the radio coverage as I drove into work this morning got me thinking.

What on one hand is viewed as an innovative interpretation of the rules is seen by others as a contravention that must be brought back into line. It resonates to a degree with Lotus in its formula one heyday when remarkable innovations from ground–effect to twin–chassis pushed the boundaries of performance.

Sadly, however, it also highlights that nowadays the rules are so constraining that little technical diversity between cars is apparent and today's "innovative interpretations" that are subject to so much scrutiny are not the same quantum leaps in innovation that Colin Chapman and his team were making. Is that a good thing for Formula 1 and its relevance to the wider automotive world? It's a subject that Jamie Turner considers in this issue.

With innovation and relevance to the industry in mind, the latest developments for Lotus's Versatile Vehicle Architecture and active noise control technologies are interesting. The Versatile Vehicle Architecture technology entering production in the Lotus Evora has resulted in Lotus being awarded the Dewar Trophy by the Royal Automobile Club. This is a fantastic recognition for everything the Lotus team has achieved and all are extremely proud. Importantly, too, the agreement with Harman International makes the Lotus suite of active noise control technologies – systems that, bringing things full circle, evolved from Lotus Formula 1 active suspension – available to OEMs for production vehicles.

Enjoy the read.

Peter Morgan
Marketing Manager – Lotus Engineering

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Industry **News**

> The Ghost will be built on its own dedicated production line at Goodwood but will share paint, wood and leather workshops with the Phantom series of cars

UK: Rolls–Royce revives famous Ghost nameplate

BMW–owned Rolls–Royce has revived a famous nameplate from its past for its upcoming new smaller model line, until now known by the codename RR4.

The new car will be called the Ghost and production will begin at the company's Goodwood manufacturing facility on the south coast of England later in 2009, CEO Tom Purves said at a Shanghai Motor Show press conference.

Purves said: "We are delighted to formally announce the Rolls–Royce Ghost. It is one of the most revered names in the automotive industry, evoking images of adventure and technical innovation. The name reflects this new model's breadth of abilities. The first cars to bear the Ghost name were known not only for impressive dependability and refinement but also great flair and style. This car will be the first in a new generation of models to carry this evocative name and will give us two pinnacle product lines – Phantom and Ghost."

The Ghost will be built on its own dedicated production line at Goodwood but will share paint, wood and leather workshops with the Phantom series of cars. Rolls–Royce has expanded all areas of its manufacturing facility over the last 18 months to prepare for the new model.

Source: just–auto.com editorial team

UK: Jaguar to launch all–new XJ next July in London

Tata Group-owned Jaguar announced a few details and released an official 'teaser' of the redesigned XJ, due to make make its public debut in London this July, at the Shanghai Auto Show.

Managing director Mike O'Driscoll confirmed that the "all–new" XJ would go on sale at the end of 2009 after its 9 July launch.

It will be the first car with the automaker's next–generation aerospace–inspired aluminium body architecture. Engine options will include the recently updated diesel V6 (a product of a Ford–PSA engine JV) and the flagship version's 510bhp supercharged V8.

In keeping with XJ tradition dating back to the early 1970s, there will be a choice of standard or long wheelbase models.

Options will include a panoramic glass roof.

Source: just–auto.com editorial team

> The alliance has also partnered with French utility company EDF and Switzerland's Energie Ouest Suisse (EOS) to develop EV recharging networks

GERMANY: ZF readies new eight–speed autobox for BMW flagship

The redesigned top-of-the range 760i due on sale next autumn will be the first BMW with ZF's new eight–speed automatic transmission.

The new transmission can also form part of a mild or full hybrid system with an electric motor which is integrated in the same installation space, ZF said.

The supplier claimed the new transmission alone would deliver fuel savings of 6% compared to its current second–generation six–speeder. The addition of an electric motor for hybrid applications would result in claimed additional fuel savings of up to 15% in mild hybrid form.

ZF also supplies numerous other components and systems for the redesigned 7–series line launched last year. These include the standard 'dynamic damping control', an advancement of ZF Sachs' CDC variable damping system which features two electronically adjustable proportional valves per damper to individually regulate the characteristics of the compression and tension stages.

That system is also cross–linked to the hydraulic ARS 'active roll stabilisation' (BMW calls it 'dynamic drive') system, also from ZF Sachs.

The 760i will also have optional 'servotronic' speed–dependent, 'active' rack and pinion steering supplied by ZF Lenksysteme, a joint venture between Robert Bosch and ZF Friedrichshafen.

The active steering option has a variable steering ratio which adapts flexibly to the driving situation. It is claimed to increase driving comfort at low speeds by providing smaller steering angles and it improves safety during evasion manoeuvres or in crosswinds by means of driver–independent steering intervention.

Source: just–auto.com editorial team

CHINA: Renault–Nissan signs zero emission deal with China

The Renault–Nissan alliance has signed a partnership with China's ministry of industry and information technology (MIIT) for a pilot programme that, it said, would be a first step in bringing zero emission vehicles (ZEVs) to the country.

The Chinese government has launched a pilot programme of new energy vehicles to be rolled out to the public transport sector in 13 cities. Nissan will provide MIIT with electric vehicle (EV) information and prepare a comprehensive plan, including a blueprint for a battery charging network and programmes for mass-marketing EVs.

Nissan will also partner with the Wuhan municipal government as the first pilot city for zero emission mobility.

"Nissan believes that zero emissions are the ultimate direction for alternative energy vehicles," said Toshiyuki Shiga, chief operating officer of Nissan. "We are establishing innovative partnerships with governments, cities and agencies to promote EVs worldwide, and in China we will work closely with our local partners to develop the EV market."

The alliance said it would bring electric vehicles to China in early 2011, making the fast-growing auto market one of the first to be supplied. In 2012, Nissan and Renault would mass market electric vehicles globally, it added.

The alliance has already started zero emission initiatives in Israel, Denmark, Portugal, Monaco, the US states of Tennessee and Oregon and in Sonoma County in northern California, and Kanagawa prefecture and Yokohama city in Japan.

The alliance has also partnered with French utility company EDF and Switzerland's Energie Ouest Suisse (EOS) to develop EV recharging networks.

Source: just–auto.com editorial team

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> The Omnivore concept features an innovative variable compression ratio system and uses a two–stroke operating cycle with direct fuel injection

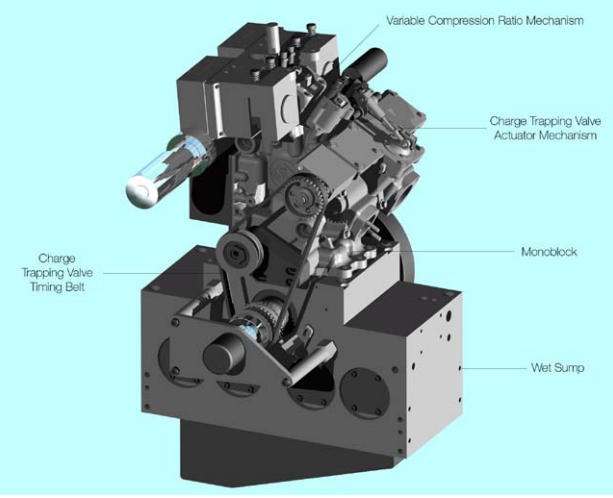
Lotus Omnivore research engine unveiled

Lotus Engineering unveiled its latest research into engine efficiency at the 79th International Geneva Motor Show.

The Omnivore engine concept has the potential to significantly increase fuel efficiency for sustainable alcohol based fuels, which increases the prospect of a greater amount of vehicle miles travelled using renewable fuels. On display was the single-cylinder research engine monoblock that demonstrates the novel architecture designed for high thermal efficiency when fuelled on any alcohol-based fuel or gasoline.

The Omnivore concept features an innovative variable compression ratio system and uses a two–stroke operating cycle with direct fuel injection. It is ideally suited to flex–fuel operation with a higher degree of optimisation than is possible with existing four-stroke engines.

The engine concept features a monoblock construction that blends the cylinder head and block together eliminating the need for a cylinder head gasket, improving durability and reducing weight. In this case, the application of a monoblock is facilitated by the absence of the requirement for poppet valves. A novel charge trapping valve in the exhaust port allows asymmetric timing of exhaust flow and continuous variation of the exhaust opening point. The variable compression ratio is achieved by the use of a puck at the top of the combustion chamber. This simple, yet effective system moves up and down affecting the change in geometric compression depending on the load demands on the engine.



In this collaboration with Queen's University Belfast and Orbital Corporation Limited Australia, with sponsorship from DEFRA/DECC and DOE NI through the Renewables Materials LINK programme, Lotus Engineering is currently testing the Omnivore single–cylinder research engine with the latest developments detailed in the next column. It uses the Orbital FlexDI fuel injection system which produces fine in–cylinder fuel preparation irrespective of fuel type, and together with air pre–mixing allows efficient two–stroke combustion and low–temperature starting, whilst offering singular opportunity for advanced HCCI control.

Latest Omnivore update

Lotus Engineering has seen a major development in the Omnivore project over the past month with the first firing of the engine taking place in Cell 41 of the test cell facilities at the Lotus headquarters in Hethel.

After burning lots of midnight oil in the recent past, the team achieved first firing of the engine on 20 March. As ever with new concept engines, it is important to proceed with caution at this critical time so after firing, the team carefully checked critical systems like the cooling circuit for any teething problems before shutting down for the weekend. They had recognised that the charge compression rig was supplying far too much airflow and this needed to be reduced. On the following Monday, with the necessary modifications made and some alterations to the fuel system completed, more firings were carried out and at approximately 6:10 pm, the engine achieved self–sustaining combustion.

The engine was gently run up to 1300 rpm crank speed where it sat happily for the next 10 minutes producing 17Nm torque. During this sustained run, the team observed 54ºC at the VCR puck coolant outlet and 50ºC at the monoblock coolant outlet with exhaust gas temperature at around 380ºC. The VCR mechanism was operated to change the compression ratio from 10:1, rising slowly to 22:1. The engine can go up to 40:1 but obviously at this point, when operating with spark ignition on gasoline, the engine would be significantly beyond the knock limit. The engine is designed to be able to vary its compression ratio specifically so that it can be optimised to explore the combustion benefits of alcohol fuels and their higher knock limit. Once the project shifts to using alcohol fuels, higher compression ratios will be used.

The Omnivore programme is another development of Lotus' research into understanding the complex combustion processes involved in running an engine on mixtures of alcohol based fuels and gasoline, which included the Lotus Exige 270E Tri–fuel, unveiled at the International Geneva Motor Show in 2008. This research is vitally important for a successful transition from today's fuels to the more efficient sustainable fuels of the future.

Source: Lotus Engineering

> The system delivers audible feedback to drivers even when the engine is silent or, alternatively, it can be used to reinforce an OEM 'sound DNA' to the end user

Lotus and Harman International announce collaboration

Lotus Engineering reaches agreement with Harman International to be granted exclusive rights for Active Noise Control technologies.

Lotus Engineering and Harman Becker have reached an agreement to jointly develop noise management solutions using Lotus' patented Active Noise Control technologies. Exclusive rights are granted to Harman Becker to manufacture the latest technology solutions for the worldwide vehicle OEM market. The agreement includes all of Lotus' Active Noise Control technologies comprising Road Noise Cancellation, Engine Order Cancellation, and Electronic Sound Synthesis.

The Road Noise Cancellation and Engine Order Cancellation systems will provide vehicle manufacturers with the ability to greatly improve in–cabin refinement, with additional design opportunities for optimising vehicle weight reduction and fuel economy.

Road Noise Cancellation and Engine Order Cancellation reduce both overall noise levels and specific audible frequencies which may be unpleasant in the cabin space. Electronic systems determine the signal needed to provide cancellation which is then seamlessly generated through the in–car entertainment system. The result is a quiet, controlled environment free of intrusive noises.

External Electronic Sound Synthesis provides specified electronic sound models which can be applied to an external speaker system to improve pedestrian safety. This is especially important for electric and hybrid vehicles which can be difficult to hear at lower speeds due to their drive mechanism. A synthesised sound, dependant on speed, is projected from speakers at the front and rear of the vehicle, making it instantly recognisable that the vehicle is in motion.

Internal Electronic Sound Synthesis allows sound contouring in the cabin, enhancing the driving experience by creating engine speed and throttle-dependant sounds audible through the in–car entertainment system. The system delivers audible feedback to drivers even when the engine is silent or, alternatively, it can be used to reinforce an OEM 'sound DNA' to the end user.

Harman International, the world–renowned high–end infotainment systems provider, will be the production system integrator and supplier, and will work with vehicle manufacturers on model-specific system architecture options. Lotus Engineering, which has over twenty years of experience in Active Noise Control technologies will assist manufacturers with system performance optimisation.

"We are delighted by this agreement with Harman International, which will allow motorists to benefit from the greater levels of refinement and safety in future vehicles which these Lotus technologies enable," said Mike Kimberley, Chief Executive Officer of Group Lotus plc. "The Active Noise Control technologies are part of a steady stream of ground–breaking innovations that Lotus has brought to the automotive industry and we are committed to pursuing further developments in vehicle refinement and environmentally friendly transport solutions."

"We are privileged to team up with Lotus for this new development initiative, which will reinforce our mission to deliver exceptional audio and infotainment experiences for automotive customers," said Dinesh C. Paliwal, Harman's Chairman and CEO. "The rich sounds of our in–car systems will be complemented by this technology, opening new opportunities for deployment and enjoyment."

"The utilisation of the Lotus suite of ANC technologies within our extensive product portfolio reinforces our commitment to support the increasing market demand for environmentally conscientious technologies," said Dr. Klaus Blickle, Chief Executive Officer and President of the Harman International Automotive Division.

The result of the Lotus and Harman International technology collaboration will be to generate Active Noise Control system solutions available to vehicle manufacturers in all worldwide markets. Working systems are ready for production implementation and manufacture. The introduction of affordable noise management systems offers multiple benefits to manufacturers and consumers alike, achieving eco–friendly optimisation of vehicle weight reductions and improved CO_2 emissions

Source: Lotus Engineering

> It is another example of a Lotus product being chosen to provide an exceptional showcase of new technologies and materials

Lotus and Evonik demonstrate new composite technology on the Evonik LWD Exige

Lotus Engineering has been commissioned by Evonik, a global leader in speciality chemicals, to construct the Evonik LWD Exige, an ultra-lightweight demonstrator based on the highly acclaimed Lotus Exige Cup 260. The Evonik LWD Exige was unveiled at the JEC Composites Show in Paris in March 2009.

As a world leader in lightweight high performance sports cars and a world-leading engineering consultancy, Lotus integrated Evonik's innovative technologies into this Exige Cup 260-derived vehicle, already a car which uses lightweight components and carbon fibre extensively. It is another example of a Lotus product being chosen to provide an exceptional showcase of new technologies and materials.

The Evonik LWD Exige demonstrator vehicle uses two Evonik materials for body panels and glazing:

• Rohacell, a rigid foam core material sandwiched between lightweight preimpregnated carbon fibre epoxy composite material, is used for new body panels which have been engineered and manufactured by Lotus. It is used extensively in Formula 1 monocoque construction and this is the first application of this sandwich composite technology on a road going sports car.

• Plexiglas, a low-cost, lightweight alternative to glass which has high break resistance and impact strength, is used for the windscreen and side windows.

Also at the JEC Composites show, Paul Sills, Executive Engineer of Lotus Engineering gave a presentation on the Eco Elise, another Lotus-based demonstrator featuring sustainable hemp, eco wool and sisal in the manufacture of its body panels, seats and interior trim.

Source: Lotus Engineering

> On the combined cycle, the Elise S shows the greatest improvement in fuel efficiency offering an increase of 3.2mpg

2010 model year Elise and Exige now cleaner than ever

For the 2010 model year, the Elise and Exige have substantially reduced CO_2 emissions and improved fuel consumption

Model	Combined		CO_2	0-60 mph	0-100 km/h
	(mpg)	(l/100km)	(g/km)	(seconds)	(seconds)
Elise S	37.2	7.6	179	5.7	6.1
Elise R	34.4	8.2	196	5.1	5.4
Elise SC	33.2	8.5	199	4.3	4.6
Exige S	33.2	8.5	199	4.5	4.7

Model	Urban		Extra Urban	
	(mpg)	(l/100km)	(mpg)	(l/100km)
Elise S	26.6	10.6	48.7	5.8
Elise R	24.4	11.6	45.6	6.2
Elise SC	23.9	11.8	44.1	6.4
Exige S	23.7	11.9	43.5	6.5

The latest Elise and Exige models are the product of continuous improvement to give up to a 9% reduction in CO_2 emissions and similar increases in fuel economy.

On the combined cycle, the Elise S shows the greatest improvement in fuel efficiency offering an increase of 3.2mpg (a decrease of 0.7 l/100km), from 34.0mpg (8.3 l/100km) to 37.2mpg (7.6 l/100km). These figures are achieved by focussing on light weight technology and small, efficient engines to achieve sensational performance and class leading fuel economy.

The exceptional balance and precise handling of Lotus cars have always been the most engaging aspect of the driving experience and these class leading attributes are now complemented by greener performance.

	Combined (l/100km - mpg)	CO2 g/km	0-100 km/h (0-62 mph)
Lotus Elise SC	**8.5 - 33.2**	**199**	**4.6**
Porsche Boxster S	9.5 - 29.7	223	5.3
Mercedes Benz SLK 55 AMG	12.0 - 23.5	288	4.9
Ferrari F430 Spider	15.2 - 18.6	345	4.1

Figures displayed above are from manufacturers' websites as at 8/4/09

Mike Kimberley, CEO of Group Lotus plc, stated: "The Lotus philosophy of performance through light weight is even more relevant in today's emission-focused ecological world. This design philosophy has enabled Lotus to offer fantastic levels of performance, with Lotus cars being some of the greenest performance cars on the market."

Lotus' cars fair well against other manufacturers of performance cars in terms of CO_2 emissions against performance. The table below compares vehicles with similar performance and highlights their emissions of CO_2. This table illustrates the efficient performance of the Elise SC.

The exciting new 2010 model year Elise and Exige are on sale now at Lotus dealers.

Elise S:
179g/km CO_2
7.6 l/100 km (37.2mpg) Combined Cycle
10.6 l/100 km (26.6mpg) Urban Cycle
5.8 l/100 km (48.7mpg) Extra Urban Cycle

Elise R:
196g/km CO_2
8.2 l/100 km (34.4mpg) Combined Cycle
11.6 l/100 km (24.4mpg) Urban Cycle
6.2 l/100 km (45.6mpg) Extra Urban Cycle

Elise SC:
199g/km CO_2
8.5 l/100 km (33.2mpg) Combined Cycle
11.8 l/100 km (23.9mpg) Urban Cycle
6.4 l/100 km (44.1mpg) Extra Urban Cycle

Exige S:
199g/km CO_2
8.5 l/100 km (33.2mpg) Combined Cycle
11.9 l/100 km (23.7mpg) Urban Cycle
6.5 litres/100 km (43.5mpg) Extra Urban Cycle

Source: Lotus Cars

> Since the Exige S2 was launched in 2004, the power has increased from 190hp through 220hp to 240hp in standard road form – more for the track-centric Exige Cup 260

The New Lotus Exige S – 2010 model year

The 79th International Geneva Motor Show saw the introduction of the exciting new 2010 model year Lotus Exige S with a newly designed front end, a new rear wing and impressive emissions of just 199g/km CO_2.

The Lotus Exige is a renowned high performance coupé that has a well-earned reputation of choice for drivers who demand uncompromising performance, both on the road and on the track.

Lotus has always pursued efficiency and fuel economy and for the 2010 model year Lotus Exige S, Lotus has reduced the emissions to only 199g/km CO_2 and increased the fuel economy to an impressive 8.5litres/100km on the Official European Combined Cycle and a frugal 6.5litres/100km on the Official European Extra Urban Cycle.

The 2010 model year also sees the introduction of a few key changes to the Exige to enhance the look and improve aerodynamic performance. A restyled front end and new larger, rear wing not only reduces drag, but also gives a more muscular stance enhancing the lightweight shrink–wrapped look of the whole car.

The composite rear wing is based on the design from the Exige GT3 road car concept shown at the Geneva Motor Show in 2007. Compared to the 2009 model year Exige tailgate mounted wing it is 181mm wider and mounted 46mm higher and 61mm further back. It is attached to the rear bodyshell clam via rear end plates which not only increases the stiffness of the whole structure but also ensures that as much of the airflow as possible passes over the rear wing. This careful airflow management increases stability, reduces drag and, most importantly, maintains the impressive downforce figures of 42kg at 160km/h.

The restyled front end includes a larger, more angular air intake mouth to help funnel more air through the radiator, to improve the efficiency of the engine system. Ahead of the front wheels on either side of the main aperture, two larger air intakes increase the airflow to the twin oil coolers. Horizontal vanes bisect these oil cooler air–intakes to stabilise the airflow to further increase the cooling efficiency.

Since the Exige S2 was launched in 2004, the power has increased from 190hp through 220hp to 240hp in standard road form – more for the track-centric Exige Cup 260 – and the new larger air intakes improve engine cooling for these current higher powered Exige variants. Mounted below the three new air intakes is a new aerodynamic splitter for the 2010 model year Exige. Made from a lightweight composite, the splitter is now extended to wrap around the whole of the front end and chiseled side lips are raised to deflect air around the tyres to reduce drag. Mike Kimberley, Chief Executive Officer of Group Lotus plc, said: “Over the years, the Lotus Exige has developed a hardcore fan base around the world and its popularity has placed it as one of the legendary sportscars of the 21st century.

“So far, over, 5000 Exiges have been hand–built at our high–tech manufacturing facility, making it a significant contributor to our global production. The lightweight Exige has one of the highest specific power outputs of any globally emissions certified car and 133hp per litre is a perfect demonstration of Colin Chapman’s philosophy of performance through light weight and of Lotus’ relentless pursuit of efficiency. The same technology that makes a lightweight car a high performer also makes it efficient – how many cars have performance figures of 0–100km/h in 4.77 secs but produce only 199g/km CO_2?”

Like all Lotus cars, the functional components of the car are also beautifully designed as Russell Carr, Chief of Lotus Design, explains, “For 2010, we have taken the already visually extreme Exige and given it even more visual drama. The changes we have integrated into the front and rear of the Exige signal an even clearer and purposeful intent. The purposeful rear wing is race inspired, the new angular air intakes and full width splitter gives a more hard–edged and aggressive look. Overall, the Exige appears more planted and gives the illusion that both the front and rear of the car are wider than they really are without losing its agile and lithe character.”

Roger Becker, Director of Vehicle Engineering, said: “The changes we have made to the Exige for 2010 model year are quite subtle when taken individually, but taken as a complete package they make significant improvements to aerodynamics and the overall look of the car. The Exige is a classic fit–for–purpose performance machine: the design tweaks we have made have reduced the drag and cleaned up the airflow around the front and rear of the car, whilst retaining the impressive balanced downforce figures, to give an exciting high performance drive.”

Source: Lotus Cars

Reforming racing to drive technology
for cleaner motoring

> “Instead of more powerful engines or better ride and handling for road automobiles, mankind has more pressing issues in the 21st century”

During the 20th century, racing provided a valuable proving ground for automotive technology which led to significant developments in engine, chassis and tyre technology as well as in aerodynamics, structures and control systems.

This was applied directly to road vehicles by many manufacturers and some, such as Lotus, Ferrari and Porsche, used the opportunities provided by innovation to rapidly improve the passenger car. However, true innovation has subsequently been dialled out of competition by the organisers' need to assuage the increasing spend by manufacturers on racing. Indeed, the worst thing for any non–innovative but high–spending team is to be faced with being completely wrong–footed by a cleverer team with a fraction of the budget but a better grasp of the opportunities provided by the regulations (the so–called 'gentlemen racers and *garagistes'*, as Enzo Ferrari referred to Colin Chapman's Team Lotus). This has given rise to restrictive regulations (which ironically force up budgets since incremental improvements on a well–optimised and tightly controlled formula are inevitably hard–won) and stagnant and irrelevant technology. While the 20th century approach was relevant then, it is not now, for while motor sport definitely improved the motor car up to about 1990, in reality road vehicles are now more advanced than their racing counterparts in most important areas (emissions, fuel economy, safety and control systems, etc.).

Instead of more powerful engines or better ride and handling for road automobiles, mankind has more pressing issues in the 21st century. Two of these are linked by carbon, or more specifically, carbon atoms currently bound in the geosphere. The need to collect them from their geographical position gives rise to an energy security issue, and their conversion into carbon dioxide and subsequent release into the atmosphere gives rise to a global warming issue. Both will need addressing at some point in the future.

Nature has seen fit to store what was originally solar energy in bond energies in hydrocarbon molecules containing these geospheric carbon atoms and has subsequently locked it into the ground. This is because the hydrogen–carbon bond is one of the most efficient ways of storing energy and the resulting hydrocarbon molecules also provide another advantage: there are a near–infinite number of ways combining hydrogen and carbon atoms, and many of the resulting molecules are either liquid or solid, making for easy storage and handling. Introducing other elements such as oxygen extends the possibilities, and the resulting carbohydrates not only make excellent fuels (in the form of the alcohols) but also foodstuffs. Where combustion engines turn the bond energy into heat through oxidation, biology releases the bond energy through the metabolic process via processes not unlike those adopted in fuel cells; it's interesting to note that chocolate has approximately the same gravimetric energy content as methanol.

The process which formed the hydrocarbons we currently burn to provide the energy to drive economic development took millions of years. In comparison, we are burning it and releasing the bound carbon atoms in the blink of an eye. Estimates for the point at which we will run out vary, but in the case of oil (currently the chief source of transport energy), even if we double what we believe we currently have then, the Environmental Protection Agency in the United States estimates that 'peak oil' – the point at which demand starts to outstrip supply – will occur between 2016 and 2028. There will then be some tough times ahead for society on a political and economic level – and in all likelihood, very soon.

In order to address the two linked global issues of energy security and global warming, mankind needs to (a) improve energy efficiency wherever possible and (b) ultimately stop releasing geospheric carbon atoms into the atmosphere as new carbon dioxide molecules. While stationary consumers of electricity can be improved by various means – including increased use of nuclear or renewable energy or so–called 'clean coal' approaches using carbon (dioxide) capture and storage, or CCS – transportation represents a serious and unique challenge, because autonomous vehicles need to carry their energy store with them. Unfortunately, storing large amounts of energy in a battery is extremely expensive and storing it as hydrogen is thermodynamically

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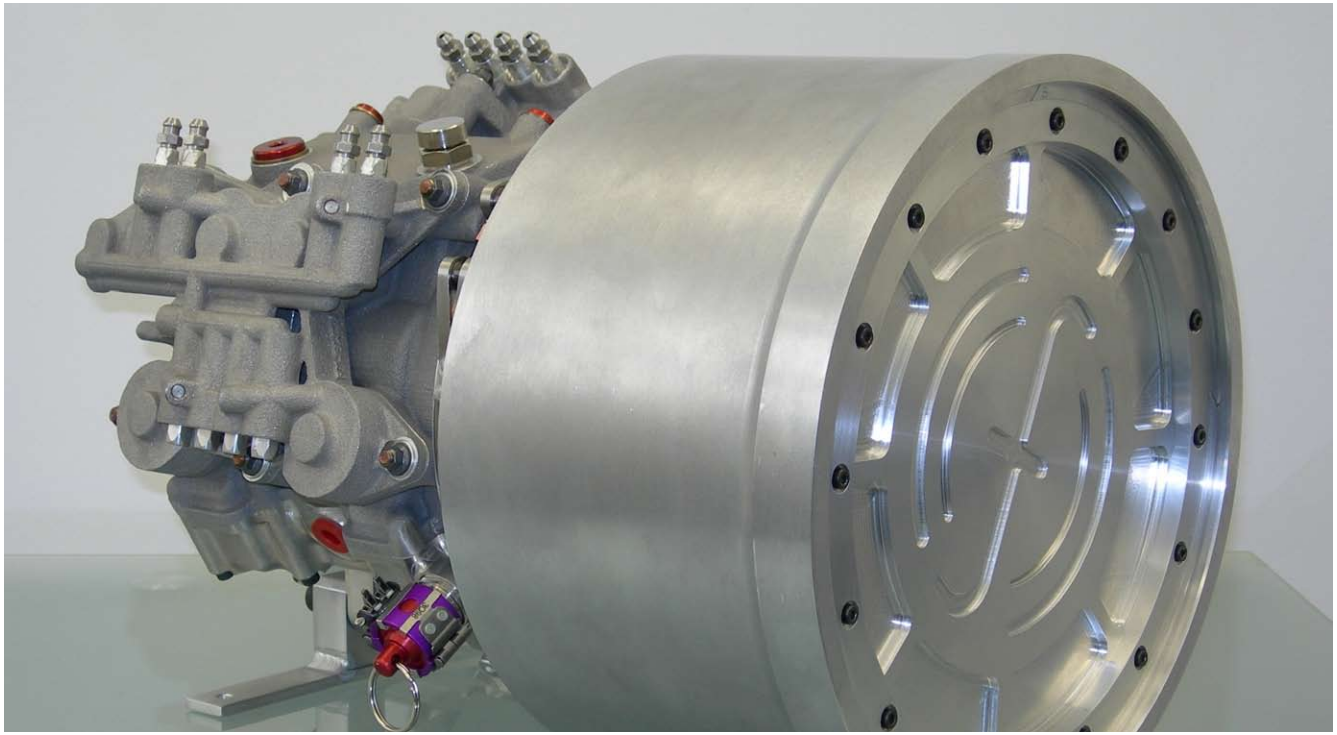
> “Racing could also be used as a means of driving the development of processes to create better fuels”



Kinetic Energy Recovery Systems (KERS) are currently in use for the Formula One 2009 season

challenging. If one uses fossil fuels then attempting to sequestrate any CO_2 produced aboard a vehicle is unlikely to be practical. These are major practical problems which face automotive engineering and which will have to be solved at some point. Against this, the 20th century template that motor sport is currently running to is entirely irrelevant.

However, Lotus does believe that motor sport can play a major role in investigating some of the potential means of achieving these aims, but that racing regulations (particularly those of the powertrain) are not currently framed in a manner to encourage this. Furthermore, regulations to help achieve this can be much simpler than those currently existing, and would undoubtedly give rise to greater variation in design solutions than is presently the case. We need to adopt a 21st century template.

In such a template, the key would be to limit the amount of energy permitted for a race distance. With such an approach, much of the complexity in the regulations as they are currently framed could be removed. There is no need for restrictions on fuel, engine and cycle types, swept volume (if applicable), means of aspiration, etc., because efficient energy conversion would be the goal: the more efficient the energy conversion, the faster the race can be run. This approach is an analogous for most people’s daily driving, only for them the aim is to complete a journey as efficiently as possible in order to spend the minimum on fuel. Both scenarios mean that, for the same fuel type, the necessary CO_2 emission will be most efficiently deployed. Furthermore, this approach also reflects the way the real car market operates – manufacturers are not forced to adopt a fixed engine type, or capacity, or fuel, because providing they comply with certain limits on emissions they can offer many different solutions to the customer.

Allowing unlimited hybridisation in racing would encourage race teams to develop efficient, lightweight solutions to the problem of maximising reuse of kinetic energy. The FIA should be applauded for its adoption of limited kinetic energy recovery systems on F1, but the regulations are nowhere near free enough. For the real world, kinetic energy reuse offers the possibility to minimise fuel consumption more than any other approach: unless cruising, a vehicle is primarily accelerating and decelerating, and even at a cruise an efficient means of harnessing transient energy would allow engines to be optimised to a greater degree within a shrunken operating envelope, to the benefit of their efficiency. At present the various legislated drive cycles around the world (being predominantly low speed) do not put a premium on kinetic energy recovery; the far more severe arena of racing would be just the forcing–house for KERS system development providing the rules are open. Hence limiting the amount of energy available for a race and permitting hybridisation would be expected to yield solutions which could rapidly and beneficially transfer to road cars. This is absolutely not the case for racing technology at present.

Racing could also be used as a means of driving the development of processes to create better fuels. Every fuel has a different energy content, so using energy as the primary limitation – rather than tank size – would allow different fuels to compete directly. One could then alter the energy allowance based on the renewability or fossil CO_2 impact of the fuel using guidelines such as are in Argonne National Laboratories’ GREET software (as used in the ALMS Green racing Challenge) to arrive at an ‘energy equivalence factor’ for a given fuel. Manufacturers and teams could then chose the best solution for them based on what would be an overall well–to–wheels assessment, i.e. the same metric that society will have to apply to energy use as peak oil is passed and the global warming becomes ever more important. The energy available and its overall efficiency of conversion would then be the important thing both in the microcosm of racing and in the wider real world. Energy, and its CO_2 impact, should be the thing binding them together so that the millions spent on race technology is not wasted finding solutions to problems which no longer exist for wider society.

Source: Jamie Turner, Lotus Engineering

Active Noise Control – taking the technologies to production

> “The computing power required to run the ANC system is now frequently present on a single chip in high–end audio systems”

Lotus began developing its Active Noise Control (ANC) – a method of cancelling out one noise by generating an equal and opposite noise – over 15 years ago

The requirement of getting the exact opposite noise in the right place at the right time when the noise inside a vehicle changes constantly was a major technical challenge, which many thought was impossible. Initial development systems used the fastest computers available with custom built hardware running custom written software. Engine Order Cancellation (EOC) was developed first followed by broadband Road Noise Cancellation (RNC). Technically, time and again, the active noise control technologies worked and produced stunning results. So what happened and why doesn’t every car on the road today use this? And why might this soon be about to change?

While there was a production application of Lotus engine noise control on the Japanese specification Nissan Bluebird in 1992, the big obstacle to wide-scale adoption was always that a cheaper and simpler solution to intrusive noise issues was always available in the form of conventional passive NVH material or other more established engine technologies (engine balance shafts). The fact that these alternative solutions usually added significant mass to the vehicle or consumed more energy was not seen as significant and ANC, although technically feasible, never succeeded as a commercial product.

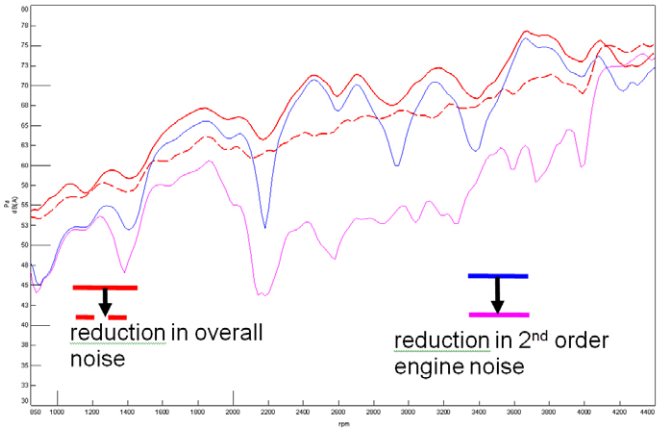
Over the last few years however, things have changed dramatically. The computing power required to run the ANC system is now frequently present on a single chip in high–end audio systems at a fraction of the cost of 15 years ago. The requirement to save energy and reduce CO2 levels mean that the conventional approaches that sidelined ANC now appear as wasteful and not acceptable. Over the last couple of years, the phone at Lotus started ringing again with customers asking if we still did ANC. Harman Becker, which is the market leader in premium in–car audio systems received five requests in a row from vehicle manufacturers requiring the option of active noise control. ANC wasn’t a dead technology; its big problem was that it was ahead of its time, and that time has now come.

Harman Becker, convinced of the market demand for the technology and the commercial value it would offer, expressed interest in acquiring exclusive rights to develop the technology for volume production. The fit of our technologies with Harman Becker’s leading-edge capabilities in audio technology and its dominance in the premium sector of the market was ideal, leading to the deal that has recently been announced and covered earlier in this issue.

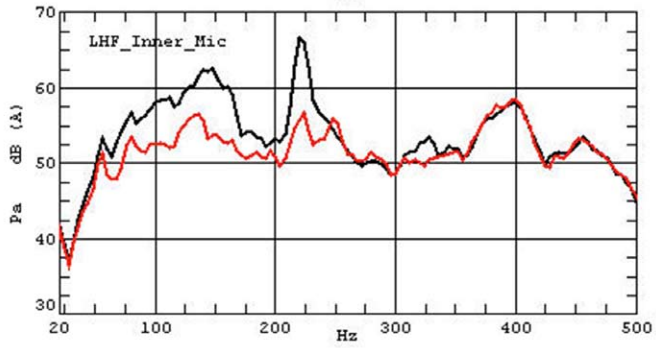
This represents a major step towards making this technology available to customers with production hardware from a highly capable and respected automotive supplier. Key questions regarding ANC system and development costs and production timescales, which were previously difficult areas for Lotus to quantify, not being a system manufacturer, can now be answered. More than this however, the complimentary acoustic skills of each company will be brought together to look for synergies that allow ANC technology to be moved to the next level and generate step improvements in performance.

The ANC technologies covered by this agreement are Engine Order Cancellation, Road Noise Cancellation and Electronic Sound Synthesis:

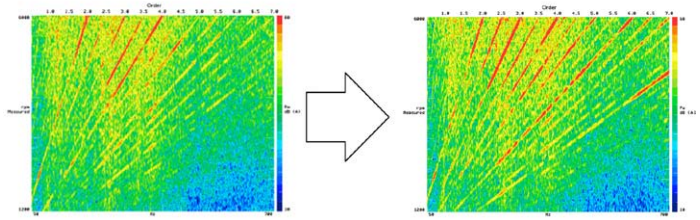
• Engine Order Cancellation (EOC) for reduction of engine generated booming noise (up to 20dB reduction on main firing frequency noise):



• Broadband Road Noise Cancellation (RNC) for reduction of suspension / road induced low frequency noise (up to 10dB reduction on dominant noise frequencies);



• Electronic Sound Synthesis (ESS) for the creation of new sound for both inside and outside the vehicle. While this is noise addition, not cancellation, it is significant as the objective is not to make a silent car, rather a car with the sound character refined appropriate to the brand. So the addition of the right type of noise can both enhance user enjoyment and safety. ESS can be used on its own or together with EOC to enhance the engine sound character or to totally change the engine sound, say from a four-cylinder to a flat 6 or V8 or V12.



Original sound 4 cylinders — Enhanced sound 6 cylinders

With the urgent requirement for manufacturers to reduce the CO2 impact of their vehicles, car buyers are expecting these environmental benefits without sacrifice to comfort and dynamics. Indeed, the demands in these areas continue to grow. This has created a resurgence of interest in technologies that can provide a step change in refinement without the penalty of additional weight.

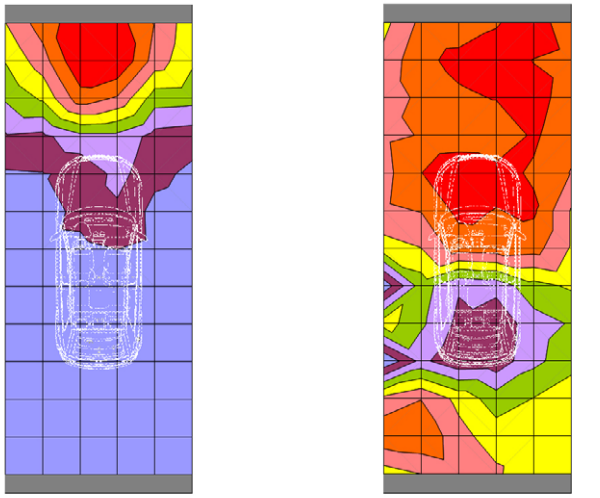
Active Noise Control – taking the technologies to production

> “Many performance cars achieve class–leading dynamics through the use of stiffened suspensions and low profile tyres”

More specific applications of the technology to enable direct CO2 savings have also been a topic of great interest, for example, deletion of engine balance shafts. The numerous ways in which ANC can be exploited in designing low CO2 vehicles has effectively enhanced its value while the potential cost of this technology has dropped with high-power, low-cost digital signal processors appearing in audio systems. The balance of point of cost versus benefit has been crossed and ANC now offers viable solutions to many of the issues facing vehicle manufacturers as they try to balance environmental demands and customer expectations for comfortable and rewarding vehicles.

Electronic Sound Synthesis for Electric and Hybrid Vehicles

The emergence of hybrid and electric drive vehicles has created an application for the Electronic Sound Synthesis technology as a means to enhance pedestrian safety. Amid growing claims that these almost silent vehicles present a significant danger to pedestrians and other road users such as cyclists, by generating an external warning sound of the right character, not only can these vehicles be made safer but also the character of the required brand identity can be enhanced.



ESS sound field | Conventional car

Interestingly, while road users ideally want a sound instantly recognisable as an approaching vehicle, manufacturers and owners of these vehicles want a distinct ‘electric vehicle’ sound. This has led to a series of new sounds being generated that are both futuristic enough to clearly not be from a conventional engine, but have enough similarities with existing engine sounds to still be recognisable as an approaching vehicle. The careful positioning and design of the speaker ensures that the generated sound is projected forward from the vehicle in a fairly tight beam – exactly where it is needed as a warning to other road users without generating undue extraneous noise.

Lower overall weight for a given level of comfort

If user comfort and enjoyment could be disregarded, then vehicles could be designed to be more environmentally friendly through reducing weight and by making smaller engines set up for maximum efficiency. ANC provides a way to exploit these technologies without a compromise to customer comfort. In addition, there are savings and benefits to the OEMs that can potentially reduce programme costs and timings.

If an ANC system is fitted to a vehicle and this effectively lowers the noise levels, there is a choice: keep the additional comfort as a product benefit, or alternatively reduce the noise treatment applied to the vehicle to get back to the original level of noise and realise a direct weight and CO2 benefit.

Improved dynamic performance

Many performance cars achieve class–leading dynamics through the use of stiffened suspensions and low profile tyres, both of which add to the low-frequency noise levels in the vehicle. We are aware of several manufacturers being forced to back off their ideal suspension settings to keep the noise in the cabin within acceptable limits. The RNC technology, by providing a step reduction in road and suspension induced noise levels, can provide more leeway to push the dynamic performance further.

Balance shaft deletion

Deletion of balance shafts from a four–cylinder engine would typically result in a direct reduction of around 3% in CO2 levels. This however leads to a direct increase in noise which in many cases would be unacceptable. Projects on this type of application have shown that all the noise increase resulting from balance shaft deletion can be regained. While a balance shaft typically consumes up to 2kW of engine power, an ANC system will require around 7–10kW. This is without considering secondary benefits of reduced weight and engine package size reduction.

Engine cylinder deactivation

For the majority of the time on public roads, large multi–cylinder engines operate at the bottom end of their power and torque capabilities. Cylinder deactivation (CDA) has been proven as a method to operate the engine in a reduced capacity and produce a 10–15% improvement in efficiency. Unfortunately when operating, say, a V8 in CDA mode, it no longer sounds like a V8. For many customers of performance cars, the characteristic engine sound is one of the key attributes they enjoy about the product. Because of this, the operating envelope for a CDA engine can often be limited by customer acceptability of noise quality. A combination of EOC and ESS can significantly widen the operating envelope of CDA use, achieving improvements in fuel economy.

Programme benefits

With increasing use of common platforms shared between manufacturers, ANC offers a way to provide a premium high–end product from a mainstream donor platform with a high level of commonality and to provide some level of brand differentiation through acoustics. In addition, the normal acoustic development between different body styles (saloon, wagon, coupé) can all be reduced as the ANC solution adapts to all vehicle types with minimal retuning.

Making it a reality

So while the benefits and relevance of Active Noise Control are numerous, the agreement reached with Harman Becker is immensely significant. For the first time through the combined expertise of Lotus and Harman, there is a clearly defined route to production for the world’s car makers. It won’t be long before these systems will be improving the refinement and safety of future vehicles.

Source: Colin Peachey, Lotus Engineering

Q&A with Dr. Pawan Goenka –
president of Mahindra Group's automotive unit

> We have taken more than 13,000 bookings on the car and sold more than 7,500 vehicles

With annual volume now exceeding 200,000 units, the Mahindra Group has become a major force within India's burgeoning auto industry. The light truck specialist has also partnered with Renault to make the Logan for the local market and is planning further expansion into overseas markets, including US market entry at the end of this year. *just-auto* editor Dave Leggett recently caught up with the head of the group's automotive division, Dr. Pawan Goenka.

DL: How's business in India right now?

PG: In India we have had a remarkable recovery in recent months. October, November and December were very bad, but a turnaround began in January, with February and March seeing good recovery for most – but not all – companies. Recovery is in all segments except for heavy trucks.

The passenger car and light commercial vehicle markets are doing very well – as are two–wheelers, also.

The feedback I am getting from the industry is that April is also fairly robust from a sales perspective. But right now no–one is willing to make a bet beyond one month...

A look at some Indian market fundamentals helps to explain where we are and what's been going on in the Indian market. Three factors stand out.

One is commodity prices. They peaked in September and forced price increases and a resultant slackening of demand. Second is financing and the availability of financing for vehicle buyers. Auto financing became very high in price and unaffordable. And third, for some segments of the market government duties have made vehicles even more expensive.

And to that could be added the overall adverse impact of economic slowdown on consumer sentiment.

The reason I feel good about the turnaround is that those negative factors have been taken care of by the government's fiscal stimulus announced in December and January. Government duties have been reduced, finance availability has improved and interest rates have come down. Also, commodity price pressures have come down to December 2007 levels.

Therefore, the market turnaround is based on fundamentals and unless they reverse, I believe we should see some growth over the course of this fiscal year.

DL: What about your export business?

PG: For Mahindra it is down significantly and we don't see a quick turnaround because demand is pretty subdued in the markets that we sell in.

DL: And Mahindra's profitability on its automotive business?

PG: I cannot talk about the fourth quarter [the quarter ending March 31] at this point because we have yet to announce results, but the third quarter was a very bad quarter for us. The automotive business was only close to break–even, for the first time in many years, and that's due to the twin effects of the commodity price increases that we could not pass on to the customer and volumes being 30–40% lower than what we're used to. So, we had low volumes and high input costs to produce a poor result in Q3. But the second quarter was better and, as I say, we're more optimistic about developments more recently.

DL: The Xylo is an interesting model – and an important one – that Mahindra recently launched in India. How's it doing?

PG: That car is doing amazingly well. We launched the car in the middle of January – the peak of the slowdown – and many people questioned the wisdom of launching a brand new product at that time. But we wanted to get some excitement and get people into the showrooms, thinking about the new product. And, fortunately for us, that's what happened.

We have taken more than 13,000 bookings on the car and sold more than 7,500 vehicles. There's a two–month waiting list of over 6,000 for the car.

There has been a tremendous response to the car. The media response was very positive and we had a very aggressive and attractive price. It's a product that is meeting customers' desires.

Q&A with Dr. Pawan Goenka –
president of Mahindra Group's automotive unit

> "We are working on electric vehicles. We have a small three–wheeler EV that we sell today"

We're very pleased with the launch of the Xylo and how things are progressing.

DL: How are your plans for US market entry later this year going?

PG: In the US market we are getting ready to launch at the end of this year – December/January let's say. We'll be starting off with pick–up trucks – two versions: two–door and four–door. And there will be an SUV about a year after that.

Technical work is all completed. We are getting ready to submit the vehicles to the EPA and homologation – the last step in the process before market launch that takes four to five months typically. After that we can launch.

In the market itself we have a fairly extensive dealer network already set up – about 300 dealers – through our US distributor. There's a lot of anticipation of the product in our dealer network as well as at the distributor.

We'll have a diesel engine that meets the strictest emission rules and we're very pleased to have achieved that.

DL: That's a Mahindra-developed diesel engine?

PG: It's a Mahindra-developed diesel engine, but in order to meet US emission requirements we have worked with some very well known consultants – from Europe.

DL: How about other overseas markets?

PG: We already have presence in several markets. The US is a late entry for us, but we have been expanding in global markets for about 40 years. Right now, our biggest continent is Africa – we have a good presence in South Africa and many other countries in Africa. About a third of our export volume comes from Africa. Neighbouring countries – Nepal, Bhutan, Bangladesh and Sri Lanka – contribute 25–30%.

The remaining overseas sales come from Central and South America – we have an assembly plant in Brazil – and also Europe. In Europe, we have a presence in a number of countries, especially Italy and Spain.

DL: How's the cooperation with Renault on the Logan going?

PG: About four years ago we agreed to introduce the Logan product in India and it was introduced about two years ago. The product has had very good reviews and acceptance from the customer.

However, because of a sudden change in the duty structure in India, the car has been penalised. Vehicles with a length under 4–metres attract 30–35% of the duty of those that are over 4–metres. Logan is the wrong side of the break. As a consequence, Logan pricing has not been competitive and volumes have been modest.

DL: Could the related Sandero hatchback be introduced to India?

PG: We are working on a business case for Sandero. Given pricing and exchange rate considerations right now, we are finding it difficult to get the business case right, but we are working on it. If it happens, we will certainly assemble the vehicle locally at the joint venture manufacturing plant where the Logan is made. But we have not yet got to the point where the business case works.

DL: What is the localisation level on parts for the Logan?

PG: We are sourcing over 50% locally. Primarily it is the engine and transmission that is imported.

DL: Where are the main efforts being directed on the engineering side?

PG: There are three main parts to this. Part one is new products to meet customer needs and our ambitions for global expansion. We currently have three new products in different segments on the drawing board which will be launched over the next two years. They include a truck that we are doing with our joint venture partner Navistar, a sub–1 tonne load carrier and a new SUV which will be a more premium SUV than the Scorpio.

The second part of the engineering effort going on is making sure that we meet all future emission standards on all products, not just in India but also in all the other major markets that we are in.

In India, from 1 April 2010 we will have emission levels changing from Euro 3 to Euro 4 in metro towns and from Euro 2 to Euro 3 in non–metro towns. So there is a lot of work going on right now to make sure that we meet that. At the same time, we know that in Europe we have to meet Euro 5 by the end of 2010, so there is work going on on that. And there is a big effort going on to meet US safety and emissions requirements ahead of US launch.

In the third bucket is advanced technologies, which includes things like hybrids, electric vehicles and hydrogen vehicles. We are looking at doing a hybrid within the next two to two-and-a-half-years.

Also, we are working on electric vehicles. We have a small three–wheeler EV that we sell today and we are working on some other electric products that we hope to be able to launch in about a year's time.

Q&A with Dr. Pawan Goenka –
president of Mahindra Group's automotive unit

> "As we move forward every year we see a lot more respect coming in for the Indian auto industry and also for Mahindra"

And we are also working on a hydrogen demonstration project with a partner.

DL: Do you think there could be a big market in India for electric vehicles?

PG: As of now the market is not big and it has to be developed. The market for electric vehicles will not develop unless there is a good partnership between government, industry and consumers. Right now the economics don't work in terms of the cost of the vehicles and the costs of electricity versus petrol or diesel. That will continue to be the case unless the government puts in some kind of subsidy and provides battery charging infrastructure.

I see the best use of electricity in the future being in, for example, the three–wheelers that we have running in a radius of 10–15km alongside the correct battery charging infrastructure and government subsidies that make the option cost neutral for the consumer. Then it can work.

DL: What do you see as the main challenges ahead for Mahindra?

PG: The biggest challenge that we see right now is that we are in a growth cycle which means that we are spending a lot of money on new capacity and new product development. On the current four–year CAPEX cycle we have committed over US$1bn – a large sum for a company of our size.

Our biggest challenge – even if there is a short–term downturn – is to keep that CAPEX intact and to generate funding to support it.

Another big challenge is that there is a lot happening on the environment and a lot of resources are going into things like meeting new emissions requirements.

And a third challenge is presented by a tremendous amount of uncertainty that is coming into the automotive business. While things don't look too bad in India in the next four-five years, we are not so sure about international automotive markets.

DL: But the poor international business climate also creates some opportunities doesn't it – perhaps on the acquisitions front?

PG: Of course there are a lot of things happening right now and several company assets are available at prices that appear very attractive. But at the same time, everybody is stretched.

We have to give priority to our billion-dollar investment programme and we have to be cautious about any acquisitions.

We wouldn't want to close the doors completely on it, but it would have to be something that aligns with our strategy. We would have to be able to afford it and we would have to be able to see what we could do with the business that the current owners could not do.

But we are not going around looking for something to invest in.

DL: What gives you the greatest satisfaction in your role?

PG: What I find most rewarding is to see how a relatively unknown Indian car company – from a car industry that is relatively unknown on a global scale – can come up and be counted. As we move forward every year we see a lot more respect coming in for the Indian auto industry and also for Mahindra. And that's what gives me the most satisfaction. It's coming from the way in which we are able to do new products, the cost and price of them, the quality improvements that we are making and so on.

And since I am vice president of SIAM [the Society of Indian Automotive Manufacturers], I also get the same sort of positive reinforcement by seeing the whole industry grow, not just my own company.

Source: Dave Leggett, just–auto.com

Dr. Pawan Goenka

Dr. Pawan Goenka joined the Mahindra Group in October 1993 as General Manager, Research & Developement, after 14 years with General Motors, US. His immediate task was to scale up the Auto Sector Research & Development, which was in a nascent stage, to a powerful product development organisation.

Under his leadership, Mahindra & Mahindra launched a slew of new products such as Pik–Up, Marshal, Armada 98, Bolero and Loadking. He is highly regarded for his leadership of the Scorpio project, which brought laurels to Mahindra & Mahindra, both in India and abroad. He became Executive Vice President – Product Development in September 2001, and was promoted to Chief Operating Officer of the Automotive Sector in April 2003. In his capacity as COO, Goenka has been responsible for day-to-day operations of the Automotive Sector. He has also played a key role in the formation of both the Renault and International Truck joint ventures. Goenka took over as President of the Automotive Sector on 26 September 2005.

Goenka received the Distinguished Alumni Award from the Indian Institute of Technology, Kanpur, in 2004 and is a Fellow of the Society of Automotive Engineers (SAE) and of the Indian National Academy of Engineers. He has been honoured by General Motors through the Charles L. McCuen Achievement Award twice, and the Extraordinary Accomplishment Award. Goenka is a member of the SIAM Executive Council and Chairman of the Committee on Frontier Technologies. He is President of SAE India and Chairman of the Management Board. He holds the position of Vice President of the ARAI Governing Council.

A Mechanical Engineer with a B.Tech from the Indian Institute of Technology, Kanpur, and a Ph.D. from Cornell University, US, Goenka has also done an Advanced Management Programme (AMP) at the Harvard Business School.

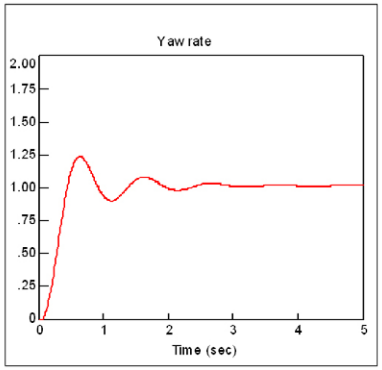
Torque Vectoring – the dynamic advantages for electric vehicles

> The ability to tune yaw behaviour via torque vectoring can potentially eliminate compromise between response and stability

Most people with an interest in vehicle dynamics will be familiar with the traditional quest for an ideal balance between conflicting attributes such as ride comfort, response, stability and fuel economy.

One emerging technique called torque vectoring is particularly suited to electric vehicles and has the potential to significantly reduce the conflict between two of these attributes, stability and response, whilst offering the opportunity to enhance the others. It is an area where Lotus has been evaluating and developing new systems and approaches.

When a driver turns the steering wheel, they expect the vehicle to change direction (yaw). The vehicle does not, however, respond immediately because tyres take time to build up lateral forces, and the actual vehicle response may not be exactly what is required, or expected. Typically, the vehicle yaw rate response to a rapid steering input is:



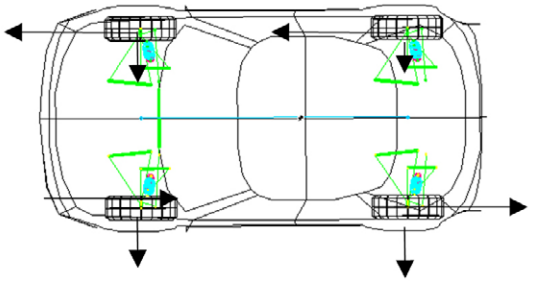
Particularly at high vehicle speed, after an initial delay period (a fraction of a second) the vehicle yaw rate can overshoot and oscillate before settling on a steady value. At very high speeds, or if the vehicle's suspension is poorly tuned, the oscillations can increase and the vehicle can go out of control. Even at lower speeds, the oscillations can make the vehicle feel less stable and the driver may find that they need to make multiple steering adjustments to follow the intended path through a corner.

Conventional vehicle suspension is tuned through bump steer, static settings, etc. to minimise the oscillations and to give a stable response at all vehicle speeds and loading conditions, but any increase in stability is at the expense of vehicle agility and the vehicle response can become dull.

This can lead to a compromise between vehicle response, stability, ride and fuel consumption. For example, tyre rolling resistance would be reduced if the suspension characteristics could be tuned to reduce tyre scrub.

When a vehicle is fitted with a means of independently controlling the drive and braking torques to each wheel (for instance electric hub motors), there is an opportunity to improve the vehicle yaw response. This is done by increasing the drive torque to the outside wheels, and creating an effective braking torque to the inside wheels. These drive torques are in addition to the normal drive torques required to control vehicle speed.

The diagram below shows drive torques helping the vehicle turn left.



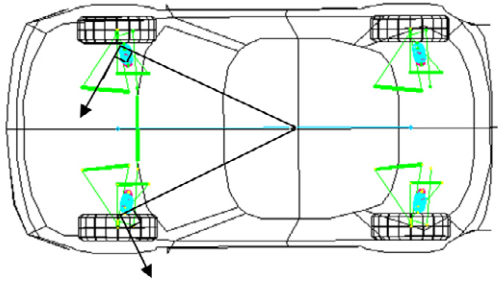
This is called Torque Vectoring and is defined as:

• Creating a difference in the braking or driving forces at each wheel to generate a yaw moment (torque) – with the intention of controlling yaw rate.

The ability to tune yaw behaviour via torque vectoring can potentially eliminate the compromise between response and stability. Suspension characteristics could be tuned to benefit ride and fuel economy; whilst torque vectoring generates the desired response.

Maximum turning moment (torque)

Independent of the steered angle of the wheels, a yaw moment is generated when the resultant of the tyre forces is perpendicular to a line through the centre of gravity. The resultant force is the combination of lateral force and driving/braking force. The maximum yaw moment (if required) is obtained when the resultant of the tyre forces is perpendicular to a line from the centre of the tyre to the vehicle centre of gravity.



Maximum moment about the centre of gravity

There are two main advantages in using these resultant forces to control vehicle yaw (as opposed to purely tyre lateral forces):

• The resultant force can act at a greater lever arm – Increasing the maximum moment available.

• Yaw rate can be controlled without requiring any steering.

If the forces are correctly controlled, the vehicle can be made to respond much quicker to a steering input and instability can be reduced. To do this the control of the wheel torques needs to consider:

• Increasing torque on the one side must be balanced by a reduction on the other side to avoid unnecessary acceleration.

• Vertical load on each wheel – particularly as the vehicle corners, the vertical load on the inner wheels reduce and drive/braking torque may cause wheel spin or wheel lock–up.

• The addition of drive or braking torques at the rear may result in loss of rear grip – leading to loss of control.

• Any response must be safe and predictable.

The challenge is how to control the torque to achieve improved yaw response and stability. For example, simply distributing the torque based on steering wheel angle would achieve more yaw response (for the same steering input), but it would not create any improvement in stability. It could even make the vehicle less predictable.

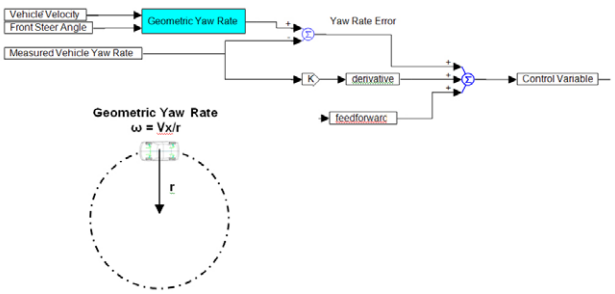
Controlling the torque via feedback control

One method to achieve rapid yaw response and improved yaw stability is to use Lotus's rear steer algorithm which Lotus developed on rear steer vehicles based on yaw rate feedback.

Torque Vectoring – the dynamic advantages for electric vehicles

> “Model-based control does not require any feedback. Instead it uses a mathematical model to predict the required input to the vehicle to achieve a desired yaw rate”

The same algorithm can be adopted to control yaw rate using torque vectoring as a controlling variable, i.e. using the signal from the algorithm as a signal to control either front or rear wheel torques.

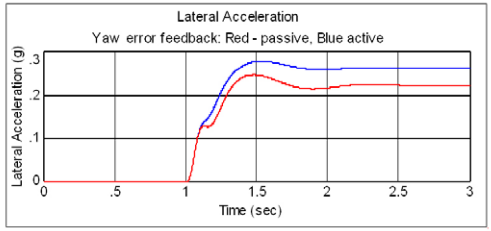


Basic rear steer algorithm

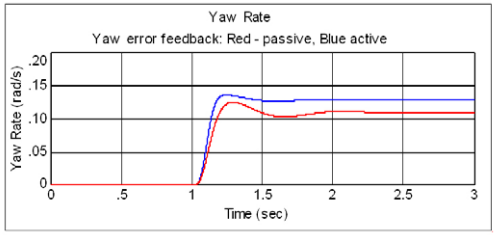
For any steer angle and forward velocity, an ideal yaw rate can be calculated by assuming no tyre slip, and using the wheel geometry to approximate the turn radius.

The measured yaw rate is then used as feedback, giving a yaw error. A differential term (yaw acceleration) is included for damping. The output is used to control the rear steer. For torque vectoring, the same signal can be used to control the distribution of drive torque, i.e for a left turn, an addition torque is applied to the right, with an equal braking torque applied to the left. These torques are in addition to the ‘normal’ drive torque that maintains the vehicle forward velocity.

Results from a step steer input are shown below. It can be seen that with the feedback system there is an increase in lateral acceleration and yaw rate, and a quicker initial gradient for yaw rate. The responses are also less oscillatory and more stable.

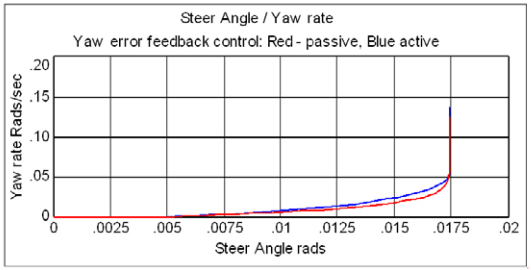


Step steer lateral acceleration response with feedback control



Step steer yaw response with feedback control

The cross plot of yaw rate and steer angle below shows a small improvement in phasing. Perfect phasing would give a straight line or linear response.



Yaw Rate / Steer angle - cross plot

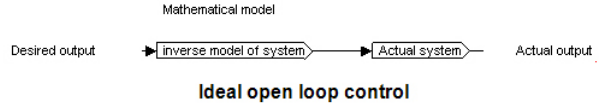
A limitation to feedback control is that the system relies on measured yaw rate as an input signal. This measured response data will also include ‘noise’ (high frequency waves created by road inputs and general vibration). In order to use the signal, the signal must be filtered. This unfortunately creates a time delay in the signal, and the feedback comes too late.

So an alternative approach is to use model-based control.

Model-based control

Model-based control does not require any feedback. Instead it uses a mathematical model to predict the required input to the vehicle (in this case driving and braking torques) to achieve a desired yaw rate. The desired yaw rate can still be calculated from the geometric turning circle (as in the feedback system) or alternatively it could be what is considered ultimately desirable, defined as a mapping.

The input to the model is therefore the desired yaw response of the vehicle (defined from the steering) and the outputs are the drive/braking torques that are required to achieve the yaw response. The mathematical model therefore represents an inverse of the actual vehicle system



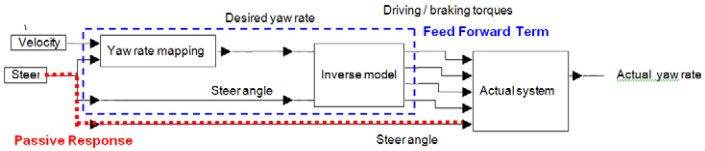
Ideal open loop control

For example a simple model could be:

This is the same as:

If the mathematical model is a good approximation to the inverse of the actual vehicle, the actual response of the vehicle will be a close match to the desired response, with no time lag or oscillations. Creating an inverse model of a complex system is sometimes not simple and sometimes not possible. Lotus has, however, created a highly realistic model that represents the inverse of a complex non–linear vehicle.

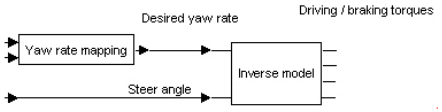
A simplified representation of the system is shown below.



Inverse drive brake torque model

The actual system therefore responds to the ‘actual’ steer input. But the natural system will tend to overshoot, respond slowly or fail to achieve the desired output – as defined by the steering/yaw rate mapping.

The additional feed forward term, below, only controls the error between the desired yaw rate and the predicted yaw rate (note this is not the measured yaw rate). This is not steer–by–wire, but enhancement–by–wire.



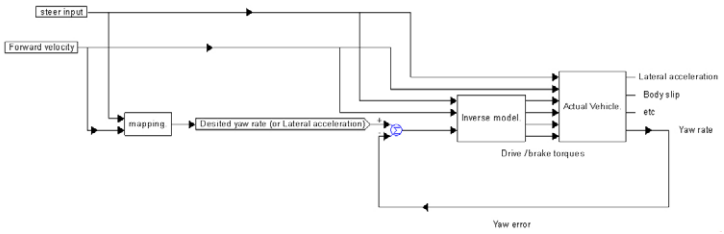
Feed forward Term

Torque Vectoring – the dynamic advantages for electric vehicles

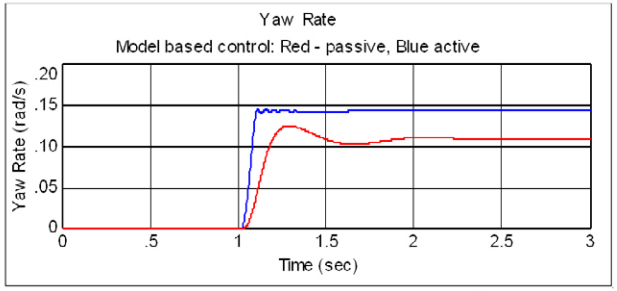
Assuming the inverse model is an accurate representation of the actual system, the output response (to an input) is rapid, without having the overshoot and stability problems that feedback systems inherently have.

Complete system

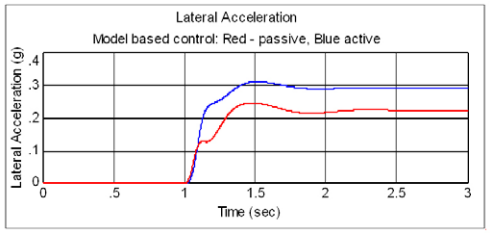
Since the mathematical model cannot always match the vehicle/road system perfectly, a feedback loop can be included to correct for the difference between the desired yaw response and the actual yaw response. The complete control system therefore combines the benefits of rapid response from the mathematical model with the feedback providing fine tuning and improving accuracy.



From the results for a step steer input, it can be seen that with the model-based system there is an increase in lateral acceleration, and yaw rate, and a much quicker initial gradient for yaw rate. The yaw response matched the demand. The responses are also less oscillatory and more stable.

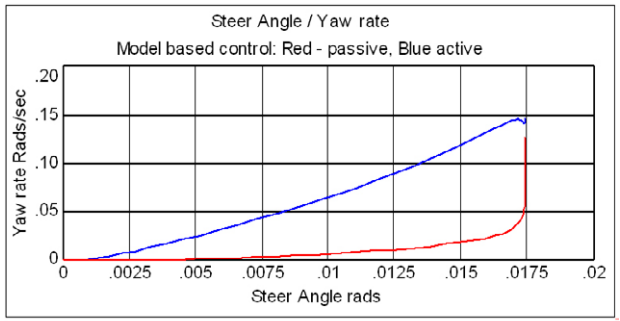


Step steer yaw rate response with model based control



Step steer lateral acceleration response with model based control

The cross plot shows a dramatic improvement in phasing of yaw rate and steer. Perfect phasing would give a straight line or linear response. This dramatic improvement shows the capability of the system but is not necessarily the desired response. Mapping response to driver expectation would require further work.



Yaw rate / Steer angle - cross plot

So in conclusion, what is evident is that although feedback control shows improvements in vehicle response to the step steer, it is the model-based control approach that has clear advantages. This approach has a dramatic improvement in step steer response, with yaw rate in phase with steering input, and elimination of yaw rate oscillations.

Torque vectoring using this approach has the potential to greatly improve response and stability, with the tuning of the control model enabling vehicle behavior to meet driver expectations. Not only can future electic vehicles have clear environmental advantages, but with the torque vectoring their drive systems allow, they can potentially be both safer and fun to drive.

Source: Malcolm Burgess, Lotus Engineering

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Contact Us

For more information, feedback or other enquiries to Lotus please contact:

Lotus Engineering

Headquarters

Hethel
Norwich
Norfolk
NR14 8EZ
United Kingdom
Editor: Peter Morgan
Email: proactive@lotuscars.co.uk

just-auto.com

c/o Aroq Ltd
Seneca House
Buntsford Park Road
Bromsgrove
B60 3DX
United Kingdom
Contact: Mike Gove
Email: mike.gove@aroq.com

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