LOTUS ENGINEERING

proActive

The official e-magazine of Lotus Engineering

The Lotus approach for world-leading driving dynamics

The concept and performance of the Lotus range extender engine

Hybrid and electric vehicle testing at Lotus

The Lotus interview: Dr Robert Hentschel, Director of Lotus Engineering

Summer 2010

ISSUE 37

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Welcome

Lotus Engineering is in an exceptional period of growth.

I saw many attractions when deciding to join the company but first and foremost, Lotus' continuous progression during difficult trading conditions proved to me the depth of knowledge and expertise in the organisation. Since joining Lotus at the turn of the year, I have been thoroughly impressed with the technical competencies on offer to others in the automotive industry.

My task is to lead the expansion of Lotus Engineering's third-party consultancy work and to further develop our position of technology leadership in lightweight architectures, driving dynamics, efficient performance and electronics and electrical integration. These key areas of expertise allow us to deliver exciting vehicles and sustainable transport solutions that are exactly aligned to the needs of the global automotive industry. We recently unveiled a prime example of this at the International Geneva Motor Show in the form of the Lotus Evora 414E Hybrid. Through the high number of advanced technologies showcased on the car, it ultimately demonstrates the exceptional ability of Lotus Engineering to integrate and develop advanced technologies for exciting, efficient, high-performance niche vehicles.

The Lotus Range Extender engine, as used on the Lotus Evora 414E Hybrid, is covered in this issue with Jamie Turner taking a deeper look at the performance of the engine. There is also an article on how Lotus Engineering developed the Lotus Evora which has won rave reviews for its exemplary handling. Finally, the issue looks at a study our North American division has carried out on behalf of the International Council on Clean Transportation, analysing new approaches for lightweight passenger cars and how other automotive manufacturers can adopt the Lotus philosophy of performance through light weight. I hope you enjoy this issue and please let us know your thoughts.

Robert Hentschel

Director of Lotus Engineering

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Lotus News

Introducing the Lotus Evora 414E hybrid

The recently held 80th International Geneva Motor Show saw Lotus Engineering unveil the Lotus Evora 414E Hybrid concept, a high-performance technology demonstrator with a plug-in series hybrid drive system and new technologies for enhanced driver involvement.

The Lotus Evora 414E Hybrid, so-named because this latest environmentally-focused technology demonstrator from Lotus Engineering produces 414PS (305kW) of power, promises breathtaking performance from a highly efficient propulsion system. The concept showcases new developments in plug-in, range-extended electric propulsion, new electronic technologies to enhance driver involvement, the adaptability of the Lotus Versatile Vehicle Architecture (VVA) that underpins the Evora 414E Hybrid and a dramatic new roof system and interior concept from Lotus Design. Through all of these aspects it ultimately demonstrates the exceptional ability of Lotus Engineering to integrate and develop advanced technologies for exciting, efficient, high performance niche vehicles.

For more information click here

Source: Lotus Engineering

Lotus News

Back in Indy!

Lotus has entered into a new technical and commercial partnership with established IndyCar competitors KV Racing Technology to run in the 2010 IndyCar Series.

The Lotus IndyCar will use the classic Racing Green and Yellow livery used on Lotus Racing cars in the 1950s and 1960s and this new livery will debut at the first US round of the IndyCar Series.

Driving the Lotus IndyCar will be the former F1 driver Takuma Sato.

Lotus competed for a number of years in the IndyCar Series in the 1960s, winning the Indianapolis 500 race outright in 1965 with the pioneering Lotus Type 38, driven by Jim Clark, and narrowly missing victory to come second in 1963.

Source: Lotus Cars

Evora carbon concept makes motorshow debut

The multi-award winning Lotus Evora provides the basis of the stunning carbon design concept. The car boasts a stylish carbon fibre, leather and alcantara interior, aggressive carbon diffuser and an evocative high-tech composite body.

The Evora Carbon Concept car emphasises Lotus' motorsport pedigree, utilising beautiful high-quality materials with exposed carbon fibre and plush alcantara. The striking white concept car is finished in an advanced water-based pearlescent paint that contrasts with the exquisitely finished weave on the carbon fibre panels.

The head turning looks of the Evora Carbon Concept car provide a more purposeful, planted stance with the car looking lower and more aggressive. This styling direction is continued with a structural carbon fibre roof, Lotus Motorsport-influenced carbon diffuser and carbon splitter. The Evora Carbon Concept car retains the same class-leading handling and high-tech aluminium bonded and extruded chassis of the production car.

Source: Lotus Cars

Lotus vehicle emissions facility upgrade

Lotus Engineering has enhanced its vehicle emissions laboratory increasing its capability and ability to test to all world-wide standards to 2015 and beyond.

To add to Lotus' long-established expertise of engine development and testing, the ability to take and measure diesel and gasoline direct injection (GDI) particulate samples in either engine test cell or vehicle laboratory environments has been the driver for a significant increase in use from Lotus' diverse client base.

Backed by extensive experience of Lotus' own engine management system, the calibration and vehicle integration departments are able to offer product development and engineering solutions for Lotus Cars future product line-up and Lotus' extensive client base.

The testing of alternative fuelled vehicles is a well-developed part of Lotus Engineering's capability that includes hybrid, bio-fuels, hydrogen, CNG, LPG and electric vehicles as well as advanced diesel and gasoline direct injection vehicles.

Lotus is able to understand and apply the requirements of conformity of production (COP) testing and apply experience to clients needs. Lotus can also provide the test facilities and the technical expertise and experience of calibration and Integration groups to provide emissions solutions. The ability to test to world-wide legislated emissions requirements as well as custom test cycles and procedures to meet client development needs in this globally recognised and approved emission test facility has strengthened Lotus Engineering's position in this area.

Lotus has planned continuous investment during 2010 which will see the acquisition of a particle count system to support development testing and COP legislative testing for gasoline, diesel and alternative fuels to Euro 6 level.

Source: Lotus Engineering

Technical Specifications

- Two test cells with twin roll 60kW chassis dynomometers;
- Euro5/6 capability temperature and humidity controlled environment;
- Speed proportional cooling fans.
- Gasoline, gasoline GDI , diesel, and alternative fuels;
- Duplex tunnel for bulk-stream handling to separate diesel and gasoline sampling;
- Independent sampling systems for gasoline and diesel;
- Separate diesel and gasoline GDI particulate sampling systems;
- Catalyst efficiency;
- Latest-generation sampling systems and computer software to deliver repeatable and accurate analysis of dilute emissions;
- Latest-generation sampling systems and computer software to deliver repeatable and accurate Analysis of raw engine out and tailpipe emissions;
- Real-time modal analysis;
- EGR;
- Gasoline and diesel particulate mass measurement using our custom built clean room weighing environment utilising a Mettler Toledo microbalance;
- CVS sampling and collection system.

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GM doubles battery research facililty

General Motors is doubling the size of what it claims is the largest and most technologically advanced automotive battery lab in the United States to increase the pace of development of electric vehicles.

It has announced a US$8m investment to improve on-site testing of all current and new battery cell, module and pack technologies by enlarging its Global Battery Systems Lab on the GM Technical Center campus in Warren, Michigan, by 30,000sq ft to 63,000sq ft

Areas previously used for engine testing will be renovated for battery development, with construction beginning this month and scheduled for completion in the summer.

GM's executive director, global electrical systems, hybrids, electric vehicles and batteries, Micky Bly, said: "GM is building on its commitment to lead the development of electric vehicle technology - from battery cell design to the charging infrastructure. This addition will benefit consumers by helping us put cleaner, more efficient vehicles, including the Chevrolet Volt electric vehicle with extended range, on the road more quickly and affordably."

The lab began operations in January last year and became fully operational the following May. It is used by over 1,000 GM engineers working on advanced batteries and electrically driven vehicles. More than half of the current lab is dedicated to testing the electrochemical battery cells and their enclosures, known as modules. The lab's remaining floor space is committed to evaluating completed battery packs.

The expansion will add capability in six areas, including:

- Safety and abuse tolerance - powertrain test cells previously used for engine altitude testing will be retrofitted for crush, penetration, water immersion, overcharge, discharge and short circuit tests.
- Buildup and teardown - reuse storage areas to prepare batteries before tests and provide secured rooms for supplier evaluation
- Manufacturing engineering - reuse space previously occupied by engine dynamometers to improve manufacturing processes, such as laser welding and cell stacking
- Charger development and integration
- Thermal development, radiant heat, thermal stability and thermal shock testing
- Battery storage

The lab equipment and test automation systems are being integrated with GM's global network of battery labs, including Mainz Kastel, Germany, and Shanghai, China.

Source: just–auto.com editorial team

NHTSA tweaks emissions rules for small-volume producers

Low-volume vehicle producers have been handed a boost following the decision by US authorities to set stringent new fuel consumption standards.

The US Department of Transportation (DOT) and the Environmental Protection Agency (EPA) have established new federal rules that set the first-ever national greenhouse gas (GHG) emissions standards in a bid to increase passenger car fuel economy.

Both bodies estimate potential savings to be in the region of US$3,000 during the life of a vehicle bought in 2016, while conserving some 1.8bn barrels of oil.

Starting with 2012 model year vehicles, the rules require automakers to improve fleet-wide fuel economy and reduce GHG emissions by around 5% per year.

The DOT's National Highway Traffic Safety Administration (NHTSA) has established fuel economy standards that strengthen each year reaching an estimated 34.1mpg for the combined industry-wide fleet for model year 2016.

Because credits for air conditioning improvements can be used to meet the EPA requirements, but not those of the NHTSA, EPA standards require that by the 2016 model-year, manufacturers must achieve a combined average vehicle emission level of 250g of carbon dioxide per mile.

The EPA standard would be equivalent to 35.5 miles per gallon if all reductions came from fuel economy improvements.

However, after consideration by the US Congress, an exemption has been made for lower-volume manufacturers such as Porsche, which has allowed the NHTSA limited authority to issue certain dispensations.

An NHTSA statement noted: "We can set another, lower standard for a particular passenger car manufacturer, only if they make fewer than 10,000 passenger cars a year worldwide.

"For those manufacturers, we set alternative standards that we determine are maximum feasible for them, on a case-by-case basis."

The NHTSA added for larger manufacturers unable to meet those standards, fines are payable under its statute.

Penalties are US$5.50 per tenth of a mpg per vehicle for the whole fleet not meeting the standard.

For purposes of determining compliance, in the case of a manufacturer controlled by another manufacturer, the vehicles produced by both automakers are pooled together.

"We are delivering on our mission and President Obama's call for a strong and coordinated national policy for fuel economy and greenhouse gas emission standards for motor vehicles, and we will do so in a way that does not compromise safety," said NHTSA administrator David Strickland.

The joint final regulation achieves the goal set by President Obama to develop a national programme to establish federal standards

Obama first announced the effort last May with a coalition of automakers, the United Auto Workers, states and the environmental community.

The NHTSA added it expected automobile manufacturers to meet these standards by "more widespread adoption of conventional technologies already in commercial use, such as more efficient engines, transmissions, tyres, aerodynamics, and materials, as well as improvements in air conditioning systems".

In conjunction with the US, Canada is also to introduce light duty vehicle greenhouse gas emissions regulations. The EPA and NHTSA have worked with Environment Canada to ensure a common North American approach.

Further details are expected from Porsche among other manufacturers.

Source: just–auto.com editorial team

Renault-Nissan alliance allies with Daimler

Renault-Nissan has confirmed widespread speculation it would enter a strategic alliance with German automaker Daimler, although the trio were at pains to insist brand identities would remain intact.

In Brussels, the alliance unveiled plans to enter into an equity exchange which will give the Franco-Japanese group a 3.1% stake in Daimler and the German automaker an identical stake in Renault and Nissan.

Specifically, the deal foresees collaboration on the next-generation Smart Fortwo and Renault Twingo, including electric versions, as well as on expanding the Smart and Twingo families.

The marriage of the trio will also include widespread powertrain development for "future applications" in passenger cars and light commercial vehicles.

This includes co-development of Renault-Nissan diesel and petrol engines for the new Smart and Twingo variants, to be "adapted and modified to Mercedes-Benz characteristics".

The manufacturers have also inked commitments to share Daimler engines for Nissan's luxury division, Infiniti, while Renault-Nissan's diesel powerplants and transmissions will be shared with the Mercedes-Benz Vito van line.

"Right away, we are strengthening our competitiveness in the small and compact car segment and we are reducing our CO_2 footprint," said Daimler management board chairman and Mercedes-Benz Cars head Dieter Zetsche in a statement.

Industry News

"We know we can make brand-typical products based on shared architectures. The individual brand identities will be unaffected."

Carlos Ghosn, chairman and CEO of the Renault-Nissan alliance, added: "We know how to work successfully in collaborative partnerships, and this experience is extremely valuable in today's and even more tomorrow's global auto industry".

The successor to the current Smart Fortwo, a new Smart four-seater and the next-generation Renault Twingo will be engineered on the basis of a jointly developed architecture.

One main characteristic of the new architecture will be the unique rear wheel drive concept used by current Smart vehicles. The launches of the jointly developed models are planned for 2013 onwards.

The Smart plant in Hambach, France will be the production location for the two seater versions while the Renault plant in Novo Mesto, Slovenia will build the four-seaters. Right from its market launch, the jointly developed future models will also be available with electric drive.

Powertrain sharing will focus on the sharing of fuel-efficient, diesel and gasoline engines between the Renault-Nissan alliance and Daimler. Renault-Nissan will provide three- and four-cylinder petrol and diesel engines to Daimler, which will then be adapted and modified.

Daimler will provide four- and six-cylinder petrol and diesel engines to Infiniti while Daimler, Renault and Nissan will also cooperate on future petrol and diesel engines.

Final production decisions for newly co-developed engines have yet to be decided.

In the LCV sector, Mercedes-Benz Vans will expand its line to include a Renault-based entry-level model, intended for commercial usage, from 2012 onwards. This will be produced at the Renault plant in Maubeuge, France. Renault has previously cooperated with Opel and Nissan on medium and large vans for Europe.

In addition to cooperating on small commercial vehicles, selected powertrain components will also be shared to enlarge mid-size van product lines and volumes. This includes a small diesel engine and transmissions which Daimler will procure from Renault-Nissan for its mid-size van, the Mercedes-Benz Vito.

The strategic cooperation will be managed by Renault-Nissan BV for the alliance and Daimler through a new cooperation committee giving representation to all parties.

Both groups maintained the deal would create a "long-term framework", with potential studies on shared modules and components between Infiniti and Mercedes-Benz vehicles, plus regional cooperation in the US, China and Japan between Infiniti and Daimler.

Source: just–auto.com editorial team

Brazil now fourth; 6m units by 2015

Roland Berger, 72, president and founder of the German consulting company, was in Brazil in mid-March, to present his market growth forecasts. And he predicted, as also forecast by other analysts, that Brazil this year will become the world's fourth-largest new vehicle market, ahead of Germany.

Ford CEO Alan Mulally, in Brazil, is just as confident. He was here to increase previously announced investments from US$2.2bn to US$2.4bn for the period 2011 through 2015.

Ford said the investment was the largest single amount it had invested in its Brazilian operations during a five-year window in its 90-year history in the country. The increased spend also takes Ford's investment in South America to $3bn through 2015.

Mulally also confirmed that Ford's Brazilian engineering team will be responsible for the new EcoSport based on the redesigned new Fiesta architecture. The redesigned compact SUV will be produced here from 2012, for both domestic and export markets.

Mulally said "For the first time in history of the 91-year old Brazilian subsidiary a vehicle fully developed by its own engineering will be manufactured in four other countries."

He did not say where, but sources told just-auto that the US, Germany, India and China are being considered.

Ford already builds sedan and hatchback versions of the Fiesta in China and its Indian unit turns out sedans based on previous-generation Fiesta architecture and has just launched a new Figo model which is essentially an updated previous-generation European Fiesta hatchback. Meanwhile, the new Fiesta, built in Mexico, will go on sale in North America, and in Brazil, later this year.

In just ten years, Brazil has climbed from tenth to fourth largest global auto market. First quarter registrations reached a record 788,000 units, 18% up on 2009's. Some industry observers are already predicting that the 3.4m-unit forecast for this year may be exceeded.

Berger, however, thinks Brazil needs to become more competitive if it aspires to become a global automotive power. He cited infrastructure problems, high taxes and bureaucracy which make it difficult for Brazilian automakers' exports to compete with vehicles from other countries, thus leading to an excessive dependence on the domestic market.

He advised: "Unite and implement an urgent work plan to improve competitiveness."

And then he announced his firm's most optimistic Brazilian forecast ever, estimating potential domestic sales of close to 6m units (both light and heavy vehicles) by around 2015.

Source: just–auto.com editorial team

A near-term approach for cost-effective mass reduction

Lotus Engineering recently concluded a comprehensive mass reduction investigation. The study, released by the International Council on Clean Transportation, was divided into two sections based on, firstly, a 2017 production target, and secondly a 2020 production target. This article reviews the nearer-term model which required demonstrated technical feasibility by 2014. A key requirement was that existing manufacturing and assembly facilities be utilised.

The total vehicle mass savings (less powertrain) were 22% (281kg) with a projected piece cost saving of 1% relative to the baseline vehicle, a 2009 Toyota Venza. This was achieved by using competitive benchmarking, applying industry-leading mass-reducing technologies, revised materials, component integration and part elimination.

The Venza established the dimensional, mass and volumetric parameters. These values were used to create the vehicle packaging constraints and to define the mass-reduction targets. The vehicle overall length and width were maintained; the occupant relationships and storage volume were also carried over. The low-mass vehicle architecture targeted a 20% vehicle mass reduction (less powertrain) and incorporated technologies feasible for a 2014 programme start and 2017 production. This architecture utilised existing facilities for manufacturing and assembly. Key suppliers were involved to support feasibility for the low-mass components, material selection, processing/assembly and cost considerations.

The powertrain investigation and analysis were performed separately by the US Environmental Protection Agency. A baseline Bill of Materials (BOM) was developed around the remaining eight major vehicle systems:

- body structure;
- closures/fenders;
- interior;
- chassis;
- front and rear bumpers;
- glazing;
- air conditioning;
- electrical/lighting.

Piece cost targets were set at a maximum increase of 20% for each system and for the total vehicle; individual components and sub-systems were not cost constrained. A piece cost of 100% was assigned to the Venza components; the low-mass piece cost factors were expressed in percentages relative to the Venza cost. The eight vehicle systems were quantified and summarised to create an overall vehicle mass and weighted piece cost estimate. Table 1. below summarises these results.

Functional objectives

The functional objectives were to maintain the 2009 Toyota Venza utility and performance including interior room, storage volume, seating, NVH (noise, vibration, harshness), weight/horsepower ratio, and driving range as well as compliance to current and near-term federal regulations.

System	Base	Mass	% Mass Reduction	Cost Factor
Body	382.50	324.78	15%	0.98
Closures/Fenders	143.02	107.61	25%	1.08
Bumpers	17.95	15.95	11%	1.03
Thermal	9.25	9.25	0%	1.00
Electrical	23.60	16.68	29%	0.95
Interior	250.60	182.00	27%	0.97
Lighting	9.90	9.90	0%	1.00
Suspension/Chassis	378.90	279.10	26%	1.00
Glazing	43.71	43.71	0%	1.00
Misc.	30.10	22.90	24%	0.99
Totals:	1289.53	1011.88	22%	
Base Venza Powertrain Mass	410.16	Mass		LD Cost
Base Venza Total Mass	1699.69	78%		99%

Table 1 – Overall vehicle mass and piece cost estimates

A near-term approach for cost-effective mass reduction

Analysis

The first four systems, body structures, closures/ fenders, interior and chassis, comprised 89% of the baseline vehicle mass.

Body structure

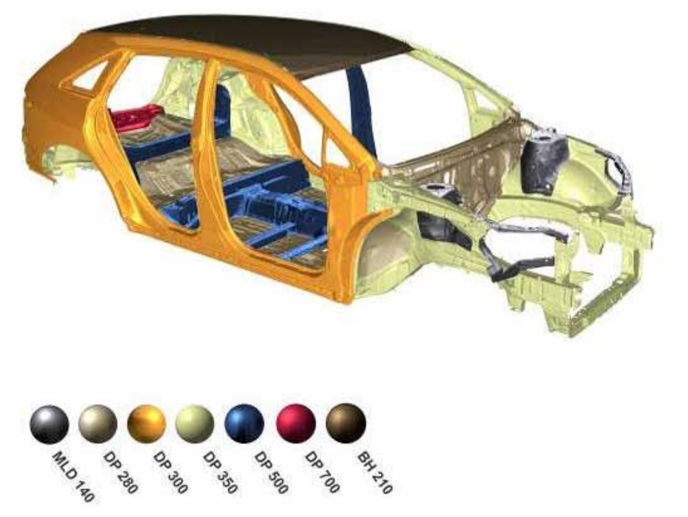


Figure 1 - The Toyota Venza higher strength steels

The Venza body in white (BIW) uses an all-steel welded structure. Spectrometer analysis indicated that the BIW was primarily mild steel with a small amount of high strength steel (HSS). A 3D model was created from scan data. The total body mass, including paint and NVH materials, was 382.5kg. The NVH and paint masses were maintained. A specific mass/volume (kg/m^3) analysis was done to determine the efficiency of the existing Venza BIW vs. other similar style vehicles. A 2007 Acura RDX 2.3 was 9% lighter on a normalised basis, indicating that the Venza was not mass optimised.

The key areas of mass reduction focus were the underbody and floor, the front structure and the body sides. A variety of thinner-gauge, increased strength steels were used including dual-phase and bake hardenable alloys to replace mild steel. The HSS content increased from 9% on the baseline vehicle to 89%. As a reference, the 2010 Mercedes Benz E class contains 72% high-strength steel.

Figure 1 shows the location for the higher-strength steels. The body in white mass was reduced by 57.7kg (15%) with a projected piece cost savings of 2% vs. the baseline Venza body in white.

Closures/fenders

Closures consist of the hood, doors and liftgate; the fenders mate to the hood and front bumper and cover the wheel openings. The study investigated composites, cast and stamped aluminium, conventional high-strength steels and evolving material technologies such as ultra high strength and dual-phase steels. Other opportunities investigated were the integration of multiple stamped parts into a single component and a higher level of modularisation to improve the efficiency of the production process. Benchmarking international vehicles, using normalised data, indicated that a mass reduction of about 50% was possible using current production closures. The Venza closure mounting hardware mass was carried over, including hinges and fasteners.

Injection molded fenders replaced the Venza steel fenders. The doors combined HSS inners with thermoplastic outers and a low-mass production based module containing the glass, glass run channels and the glass lift mechanism. The tailgate used a magnesium casting inner structure and a thermoplastic outer. The hood outer and inner were constructed of aluminium. The total mass savings for closures was 35.4kg (25%) with a piece cost of +8%.

Interior

The interior consisted of the seats, instrument panel, hard and soft trim, carpeting, controls, console, restraints and HVAC module and air distribution ducting. The primary philosophy of the mass reduction of the interior module was to create mass savings that were consumer neutral or positive, meaning the interior retained design, comfort, function and consumer acceptance compared to the 2009 Venza interior.

Venza Baseline Front Seat

Hyundai Azera Magnesium Casting

The Ford Fiesta seat was selected for the front seats based on benchmarking results. The Fiesta seat was lightened further by using a cast magnesium frame from the Hyundai Azera. A Venza side air bag and volume adjusted seat cushions from the Fiesta

A near-term approach for cost-effective mass reduction

Low-mass interior

Baseline Venza interior

Central touch screen control unit

were incorporated into the low-mass seat. A Chrysler 300 power seat unit, the lightest benchmarked assembly, was used on the driver side. The driver seat mass reduction was 24% with projected cost savings of 12%. The non-power passenger seat mass reduction was 41% with projected cost savings of 12%.

The Venza fold-down rear seat incorporated a 60/40 split and a rear compartment release that allowed the seats to fold forward. The Nissan Qashqai was selected as a representative low-mass rear seat. The Venza rear seat carried 8kg of mass for elements required to adopt this seat, carried over from other Toyota platforms, to the Venza. The Qashqai rear seat utilised an all foam lower seat with a simple floor-mounted pivot for fold flat capability. In order to normalise the functionality to the Venza, the remote folding mechanism and handle were added to the mass build up. The seat back mass was reduced another 3 kg vs. the Qashqai seat by using roll forming and laser welding; the General Motors Malibu/LaCrosse production seat back uses this construction. The rear seat mass was reduced by 43% with projected piece cost savings of 12%.

The instrument panel appearance was retained as well as all functional features; the baseline and low-mass IPs are shown in above. The electronics and switches, as well as the ventilation system, transmission and park brake controls were consolidated into a central touch screen control shown in above. This eliminated the mechanical foot operated parking brake mechanism, the transmission gear selector lever, the HVA/C control and the radio and saved 7kg. The touch screen integrates 3D haptic feedback for ease of use. Eliminating the shifter, radio and HVA/C control increased storage space at the front of the console.

Other interior systems

The center console was based on a Volvo S40 production unit and incorporated a revised support structure and a low density foamed plastic. The mass reduction was 31%; the estimated piece cost was the same as the Venza console piece cost. The noise insulation was reduced 1.6 kg based on supplier input; the estimated piece cost was the same as the Venza. The foamed plastic was also used for the hard trim and door panel trim; the mass reduction was 20% at a projected 5% piece cost increase. The door release mechanism used an electric push button system similar to the 2009 Corvette to reduce mass. The soft trim, including carpeting, headliner, and sun visors, was carried over. The HVA/C mass was reduced by using the foamed plastic; the Venza airbags were carried over. Other interior systems investigated included pedals, steering column and steering wheel.

The total mass reduction for the interior was 68.6kg (27%) with a projected piece cost savings of 3%. The majority of the mass reduction came from benchmarking current low-mass systems and sub-systems; the low density foamed plastic also contributed.

Chassis

The chassis system consisted of front and rear suspensions and cradles, wheels, tyres, and brakes. The Venza payload capacity of 549kg was retained. The reduction in gross vehicle weight (GVW) was 14%. This significant total vehicle mass reduction allowed the suspension, tyre and wheel components to be lightened linearly as a function of the curb weight. Additional mass reductions came from using a magnesium front suspension cradle, HSS springs, aluminium knuckles, and a hollow front stabiliser bar. All of these low-mass components are used on production vehicles. 19” wheels and tyres were mandated; however, the wheel width and the tyre section were reduced because of the lower vehicle curb weight. A smaller spare tyre and a lighter jack were also used. The wheel and tire mass savings was 35.6kg.

The Venza chassis mass was reduced by 103.4kg (27%); the projected piece cost was the same as the Venza.

Front and Rear Bumpers, Glazing, Air Conditioning, Electrical/Lighting and Miscellaneous

The above systems comprised 11% of the baseline vehicle mass; their combined impact on the vehicle mass was relatively small.

The air conditioning system consisted of the compressor, condenser, and lines. Benchmarking showed the mass of these components is relatively independent of vehicle size. Additionally, there is no clear consensus for a mobile system refrigerant at this point in time. Because of these factors, the Venza underhood AC mass and cost were carried over.

The electrical system incorporated copper-clad aluminium wiring (CCA) used successfully by the home audio market to reduce cost. The estimated mass savings was 6.9kg (29%) with projected piece cost savings of 5%. The Venza lighting mass and cost was used to eliminate any potential for including a lighting system that was not comparable in performance to the current Venza system.

The bumper system incorporated an aluminium front bumper rather than the Venza steel bumper; the Venza rear bumper beam is aluminium. The estimated mass savings was 2.0kg (11%). The Venza front and rear fascias were carried over. The estimated bumper system piece cost increase was 3%.

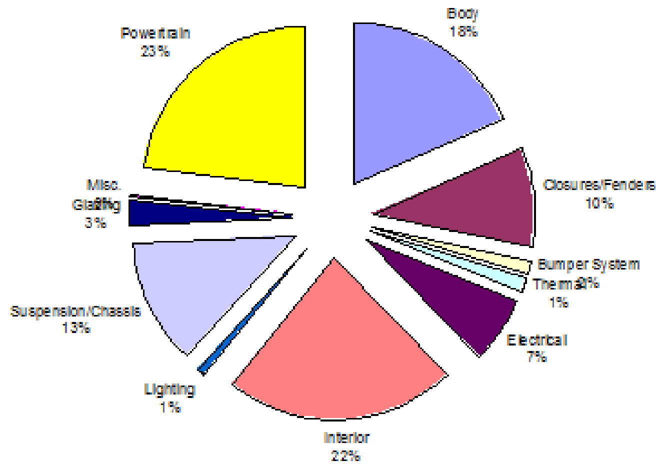
The Venza glazing mass and piece cost was carried over. Silicate coated polycarbonate has long-term potential to reduce mass significantly for fixed glass applications but was not selected for this timeframe.

There were a variety of miscellaneous components that were mass reduced such as the windshield wiper system; the mass savings was 7.2kg for this group with a 1% cost reduction.

Cost weighting

The graph to the right lists the estimated manufacturing cost contribution for each system to the total vehicle assembled cost. It is an approximation that will vary from OEM to OEM. Multiplying the piece cost factor by the system cost contribution (i.e., the weighting factor) and summing all vehicle systems gives the estimated total vehicle piece cost for the low mass vehicle. As an example, the body in white cost factor (98%) times the vehicle system piece cost (18%) yields a new value of 17.6% for the body. Performing this calculation for each system yields an estimated total vehicle piece cost of 99%. This is a 1% piece cost reduction compared to the baseline Venza and is included in Table 1. in the opening “Summary” section.

This study focused on the use of lightweight materials, efficient design and demonstrated substantial mass savings and highlights how automotive manufacturers can adopt the Lotus philosophy of performance



Estimated vehicle costs

through light weight. We believe that this approach will be commonplace in the industry for the future design of vehicles.

Source: Gregg Peterson, Senior Technical Specialist, Lotus Engineering Incorporated

LOTUS ENGINEERING

The Lotus interview: Dr Robert Hentschel, Director of Lotus Engineering

This is the first in a new series of interviews with people at Lotus Engineering.

just-auto's Dave Leggett interviews Dr Robert Hentschel, Director of Lotus Engineering

DL: You have worked in Germany, the US and China in the past, and now UK. What did you make of the differences in approach?

RH: There are, of course, different cultural attitudes around the world, different ways of life and of doing business. In China, you learn how to negotiate; in Germany, things are very structured – and perhaps they are a little less so in the US, but there is a very optimistic attitude in the US.

In the UK, there is a very traditionalist approach, which has its advantages, too. I try to learn from the most positive aspects of the different mentalities to bring the best mix of approaches to the business.

DL: Having taken up your position as Lotus Engineering CEO early this year and moving to the UK, what have been your first impressions?

RH: I write down the first impressions early on, because you soon become part of the organisation and lose that initial perspective.

We have very good technology and capability in electrical integration, electric motor and drivetrain integration. We have well-known expertise in driving and handling, lightweight architecture.

There are a lot of people with long-term service at Lotus.

There has been a big change recently to get everyone motivated alongside important changes in the upper management of the organisation since October. That has generated some excitement in the organisation.

DL: There's a mix, then, of the traditional strengths alongside some change in attitude or culture within Lotus?

RH: Yes, tradition is good for the benefits of experience that come with it, but tradition must not work against beneficial change. I am working hard to implement changes.

DL: And what are the most important changes you think need to be made?

RH: First of all it is important to have a medium-term business plan. We are in the first year of a five-year business plan. It is vital to get the house in order from a business perspective.

But it is also important to ask the question: what can we say to other markets? We have so many technologies and so much research experience, but the first thing is to establish what we are capable of and what people in the market want, across the world.

A priority is China, because customers there like and know Lotus and it will be an important growth market for our capabilities. We have to focus on building up our organisation in China.

We are also watching developments with new niche OEMs looking at the US and especially new growth opportunities on the West coast.

DL: You see new entrants to the auto industry as presenting a bigger opportunity for Lotus than working with established players?

RH: Yes, I think so. Electric and hybrid vehicles are still a niche. In Geneva, a big OEM contacted us and asked us how we can develop our vehicles at such

Dr Hentschel behind the wheel of the Lotus Evora 414E Hybrid

low cost. I think they come to us to learn from us, but the core issue for them is the process they have. We have a much leaner process.

Because electric and hybrid is a core competence for us, it's a niche and we have excellent solutions for new OEMs who want low-cost niche vehicles.

We can offer four key things:

- efficient performance;
- lightweight architecture;
- electrics/electronic integration;
- driving dynamics.

If you look at these four areas of Lotus expertise, they can combine to give us a very strong niche vehicle capability.

And we want to position ourselves in a high-technology area – we have unique capabilities - with these four core elements and bringing them together to produce niche vehicles.

DL: But there must be wide differences in terms of what you are being asked to do?

RH: Yes, there are. In Europe and the US, we are being asked to do things based on these four competencies. In Asia, many companies are still learning how to develop vehicles, normal vehicles, and they are still learning about process management and things like that.

But I think I would like to prepare Lotus with a presence in China for when technology comes back from China in the future. They are learning very quickly about electro-mobility.

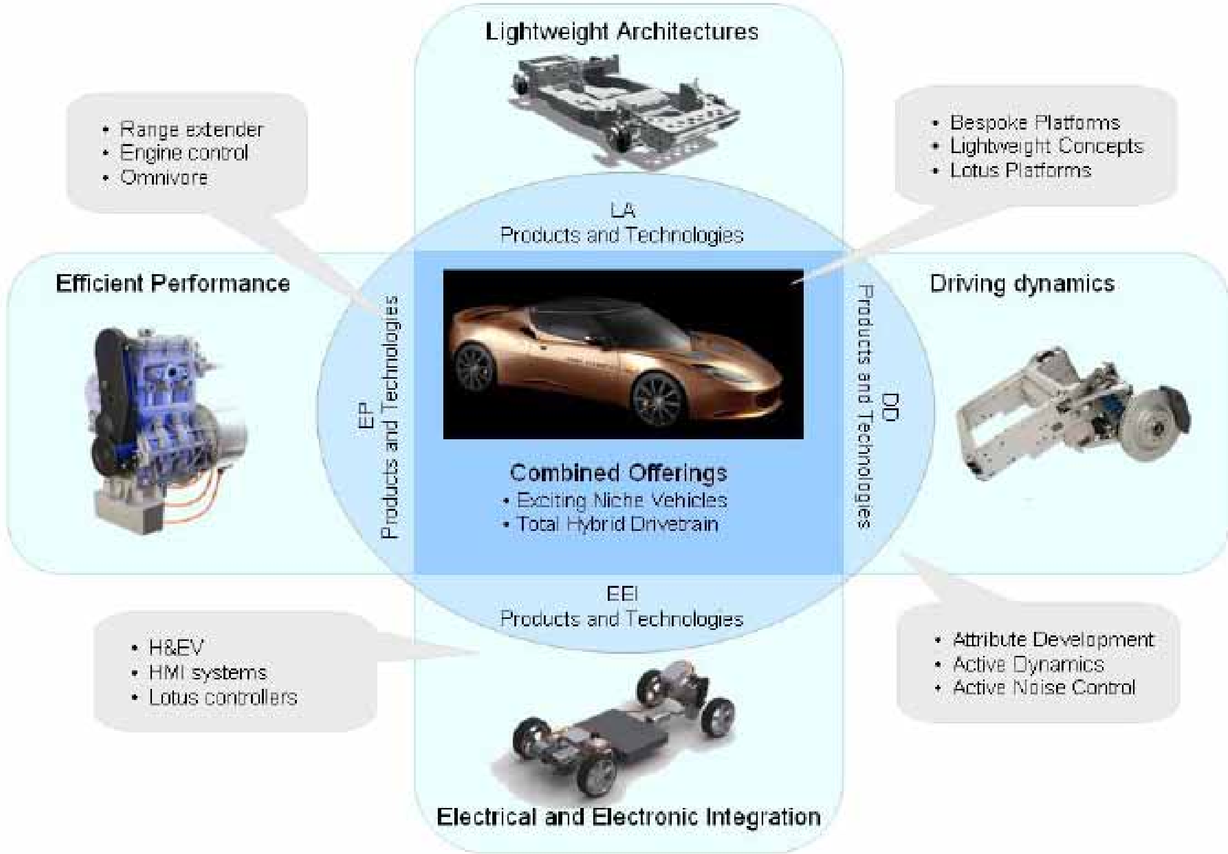
DL: And what is your physical presence in China currently?

RH: At the moment we have a sales office in Shanghai, with 12 people. We have to build up a local base in China. We have to train people with our core competencies. But I'm also interested in looking for partnerships because I think growing organically is a long-term process.

DL: What do you see as the types of vehicle that will be of growing importance in the future?

RH: I think there will be a focus on urban mobility, with smaller and lighter vehicles, but still with sports performance retained. I see an opportunity for intelligent lightweight structures with high performance and with the functions you need to live in the city. I think there will be a focus on connecting the car to the local infrastructure and getting information from it.

People are becoming more aware of intelligent mobility. There is a mindset change going on. People are thinking greener and I think they will be receptive



Lotus Engineering's core competencies

to additional functionalities or helpful information that makes the journey better in some way.

DL: So enhanced connectivity is something that you see as a growth area?

RH: Yes, and if you think about niche vehicles they are particularly going to be a focus for new connectivity services. Niche vehicles are not high-volume products; the customer is paying a premium for something special; they want to be different. And I can see a big opportunity for Lotus in partnering with other specialists to provide the added functionality and services that drivers of niche vehicles will be increasingly demanding through intelligent mobility.

Source: just–auto.com editorial team

The Lotus approach for world-leading driving dynamics

For the Lotus Evora, the brief was simple; to design the best handling car in the world. Although a tall order, Lotus Engineering has a reputation for producing vehicles with exemplary handling and has an enviable track record in developing world-class vehicles for Lotus Cars and other global automotive manufacturers.

Currently, the Lotus Elise and Exige are considered benchmarks for driving dynamics and moving from this platform to the Evora was a big step. The former are highly focused sports cars that make few compromises, especially when it comes to handling. The Evora is a very different beast altogether. It sees the re-introduction of power-assisted steering to the Lotus line up along with an increase in the weight and power output of the vehicle. The Evora had to offer the same sort of driver involvement and feel as its smaller stable mate but with an air of elegance and increased refinement that you would expect from a vehicle in its class.

How does Lotus go about designing the suspension system on a vehicle to deliver world-class ride and handling? Well the process was the same for the Evora as it is for any of the work that we carry out for our numerous third-party clients.

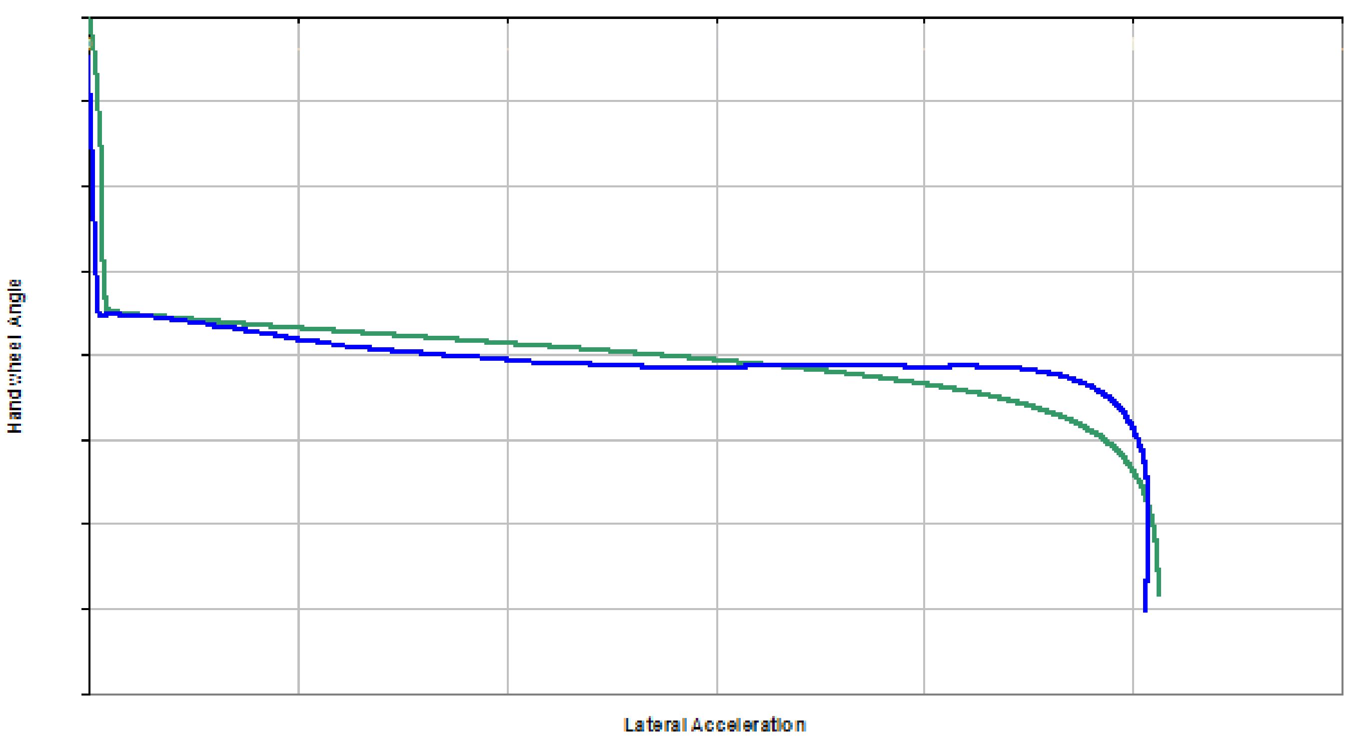
We start off with a benchmarking activity using vehicles carefully chosen for specific attributes. After carrying out objective and subjective assessments of the vehicles we will also carry out objective suspension compliance tests on our custom designed SKCMS rig. This rig test does two things: the first is it gives us an insight into the suspension kinematics and compliance that our competitors use and it also allows us to create handling models that we can run using our RAVEN full vehicle handling software. This allows us to directly compare the handling responses of the vehicles, with one distinct advantage, that we can individually change any parameter such as mass, weight distribution, ride height or suspension characteristics. We can then model the vehicles driving on the same tyre to directly compare the responses, as in some cases it is impossible to compare otherwise. This is the start of the target setting process; not an activity that is carried out in isolation by the vehicle dynamics CAE engineers.

At Lotus we feel that involving the whole development team from this stage is vital to ensure that there is a coherent direction for the vehicle. The development engineers can directly feedback their understanding of the competitor vehicles gained during the benchmarking activities. This allows us to drill down through the vehicle assessments to understand the fundamental vehicle attributes that define the other vehicles and therefore how we will define our attributes. Using RAVEN we start to create a vehicle model that represents the vehicle. The concept parameters used include wheelbase, track and mass estimates and are developed to include all the kinematic and compliant characteristics that will define the handling response of the vehicle. The steering response of the Evora is a great example of this. When we were discussing the Evora concept, we were given the target of class-leading response. For us, this is not just one characteristic but a number of characteristics that add up to the finished product. We must remember that the way the vehicle responds to a steering input is the result of the combined effect of many of the K&C characteristics and not just a few. Rather than talking about the specific Evora suspension characteristics, I will talk more openly about the attributes that we target in order to attain the response required. There are a number of properties that add up to give a great steering response. As we move through our set of standard manoeuvres, we build a picture of how the vehicle is responding and develop it as we go. We would normally start off with a very basic model with an assumed ride rate and then we develop this with the addition of roll centre heights to attain the initial roll gain targets. We build on this with the camber and toe change in the roll to derive a basic level of understeer in the system. Once the initial kinematic targets are developed, we then work on the compliance in the system to hone the consistency of that response.

An important attribute is steering linearity. In setting targets for the response linearity we wanted to ensure that the vehicles response to handwheel inputs is as linear as possible. We define this using a steady state cornering manoeuvre. The steady state manoeuvre is one where the vehicle is driven around a turning pad and slowly accelerated. The driver, real or simulated, then changes the handwheel angle and the lateral acceleration generated by the vehicle at steady state. For example, a steady state understeer gradient of 40 degrees per ‘g’ demonstrates that for our given turning circle diameter, a handwheel angle of 40 degrees will produce 1g or 9.81ms^{-2} of lateral acceleration to the vehicle. The linearity of the vehicle response across the lateral acceleration range is very important in instilling driver confidence.

Figure 1 shows two vehicles all in the same class and their differing lateral accelerations. The gradient of the line slopping downwards towards the x axis indicates understeer. We are dialling in the level of understeer that we would like the vehicle to have. We can see that the green plot shows a vehicle with good steering linearity where the vehicle will respond at the same level throughout the manoeuvre, whereas’ the vehicle depicted in the blue line shows a response that has less linearity. The blue vehicles’ response will be more difficult to predict. If the understeer gradient deviates from a constant level, then the driver can find it difficult to predict the response. Generally, it can be acceptable to have an increasing level as lateral acceleration builds as this is a very safe response, however it does make the vehicle feel less responsive. We chose our level of understeer to give the driver a very responsive feel. Maintaining this gives the security to exploit the capabilities of the vehicle. Towards the limit we reduce the responsiveness of the

Figure 1 - Steady State Understeer Plot



vehicle to give the driver fair warning that the limit is on its way. We do this by increasing the understeer gradient, to reach around 4x that of the linear region, by around 0.1g before the limit. Looking at the second vehicle again, over the first third of the plot, we can see that the gradient is increasing so the driver needs to increase the additional handwheel required. This goes up disproportionately to the additional lateral acceleration attained. Then, during the middle section, the gradient tends towards zero and possibly slightly positive. In this oversteering condition, the driver would have to remove steer angle to maintain the correct heading. So, in the space of 0.5g we have gone from a relatively high understeer gradient requiring high levels of steering input to an oversteering condition where the vehicle response is very sensitive to steer angle changes. This is an extreme example but it does demonstrate how the lack of linearity would ultimately compromise the driver's ability to predict the required steer input for a given turn. Even though in this case as we approach the limit it is a very safe to increase the additional handwheel input.

Similar tests are performed using a constant speed rather than radius and these are repeated at a number of different vehicle speeds.

We would then move on to the step steer responses. Again using our RAVEN analysis tool we subject the vehicle to various sharp steering inputs across a number of forward speeds. We try to ensure that the vehicle response levels are consistent across the range of speeds and handwheel inputs, setting a consistent level of yaw gain (the rate of response to the steering input) and yaw damping (the stability of that response). Step steer responses to analyse the

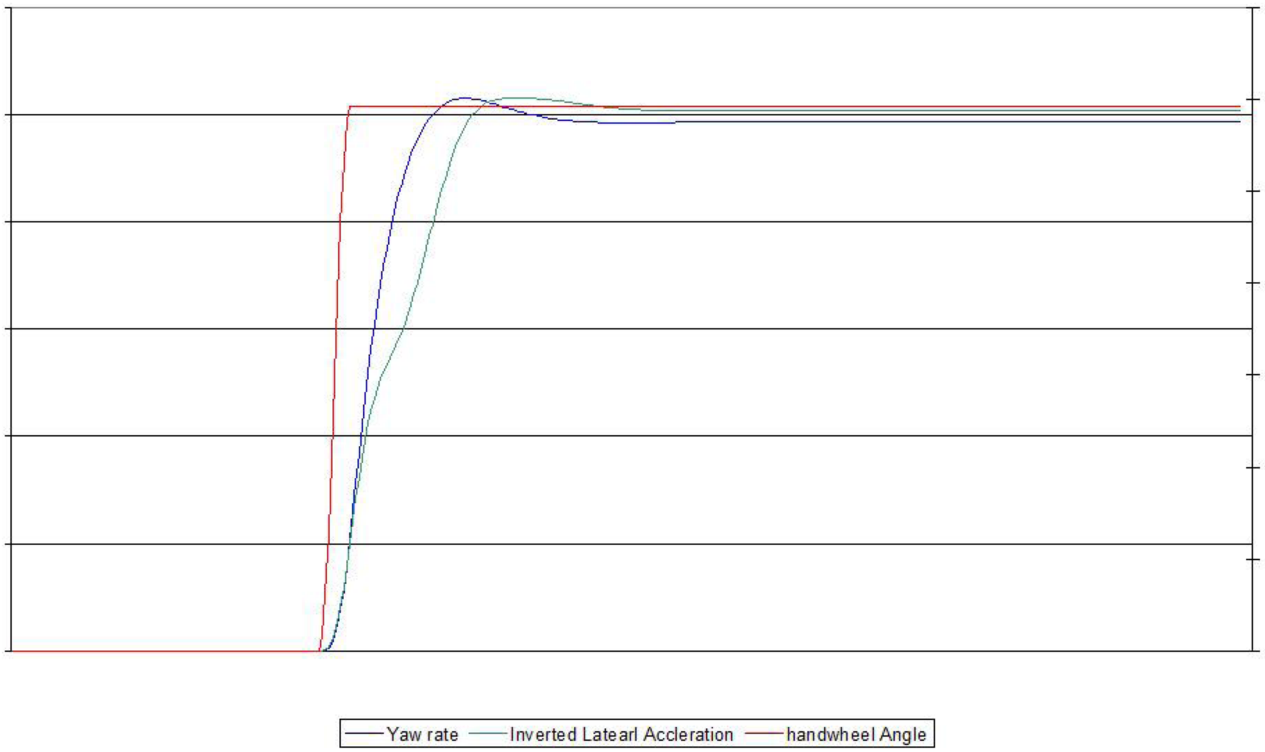


Figure 2 – Step steer manoeuvre

phasing of the lateral acceleration and yaw velocity response of the vehicle. Looking at the phasing in this way allows us to consider how the vehicle is responding to the driver input. We can see from Figure 2 that the yaw response leads the lateral acceleration; the driver will feel the car turn in just as the lateral acceleration is building up. This gives a greater feeling of control and improved responsiveness. If the lateral acceleration builds too quickly and leads the yaw response, the feeling would be very different. Building up lateral forces before the car turns in would feel sluggish and unresponsive. Building up yaw rate too quickly however, would feel less stable.

Once the targets have been developed and proven out through the full suite of handling manoeuvres, we can compare the concept vehicle responses of the benchmark vehicles. This allows us to check that we are reaching the levels of response needed.

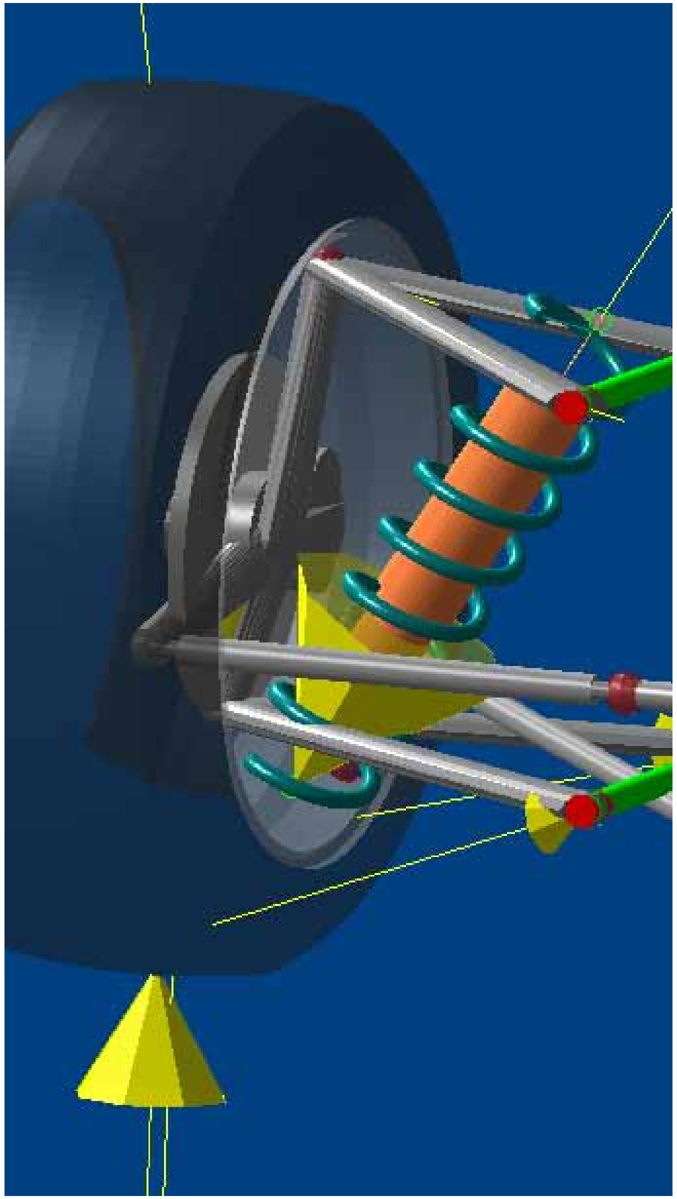
When we are happy that we have achieved the desired characteristics, it is time to cascade the targets down to the subsystem levels. This involves using the second piece of in house software, SHARK. This is our subsystem modelling tool that allows us to develop a compliant model of the suspension system. Having set a comprehensive set of targets, we can now work with the package team and build a suspension system that will meet these targets. At this stage, the close relationship between the vehicle design group and the vehicle dynamics CAE team comes into its own and literally dozens of iterations can be evaluated in a very short period of time. We can change suspension hardpoints in real time and very quickly evaluate changes in compliant characteristics. Once the initial kinematic targets have been reached, we then move on to developing the compliant solution. Initially working with combined hardpoint stiffness, we then develop the model to include bushes and local hardpoint structural stiffness. Stiffness of the wheel bearings, suspension knuckles and even wishbones can be considered and optimised. Our aim is to deliver a solution that will tick every box without compromising any other vehicle system.

Once the subsystem models have reached a suitable level of maturity we can use the tyre forces generated during the steady state manoeuvre within SHARK to predict the steering efforts. We do this by combining the vehicle motion, to articulate the suspension system to the correct orientation and to the tyre forces as measured throughout the different manoeuvres. These combined with a model to the steering system gives us a torque at the handwheel. We use this to design evaluate the exact level of assistance required in the power assisted steering system for all aspects of the vehicle performance envelope and this can be fed back to the project group.

As we move through the project, we continue to develop and check both the subsystem and full vehicle models to ensure that we continue to attain the desired levels of vehicle response. Working closely with the design and development team throughout the programme ensures that, that the maximum benefit of the modelling is made. During the prototype build and development process, the highly detailed models can be used with great effect to provide iinstant feedback on changes to bushes, bars, geometry and steer components.

In an example of how we used this model to reduce the development time on the Lotus Evora, one of the development engineers wanted to look at how the levels of response would change when bush stiffness was changed. Within a matter of hours, we had created specific models for the bush arrangements and run them first through Shark to assess the impact on the K&C and then through RAVEN to see how the handling response changed. This was carried out in the days prior to the development bushes being available and, as a result, fewer permutations were tried, saving valuable time and effort in what was already an incredibly challenging timing plan.

Source: Steve Williams, Vehicle Dynamics, Lotus Engineering



The concept and performance of the Lotus range extender engine

The Lotus Range Extender engine is a purpose-designed 1.2 litre in-line 3-cylinder spark-ignition (SI) engine for use in plug-in hybrid electric vehicles.

Because of this clearly-defined role, some of its architecture can and does differ from the current automotive norm (while not deviating from accepted automotive materials and processes which ensures its production feasibility). In this respect it is completely unlike some other potential range extenders such as hydrogen fuel cells and is also less radical than some solutions which can be considered more economically viable such as the Wankel engine or gas turbine. While both of the latter concepts may be feasible to use as a range extender in the longer term, the Lotus solution of a reciprocating 4-stroke SI engine is believed pragmatic for the present-day, enabling its rapid introduction to an emerging market with minimum risk for new and existing manufacturers alike. This article discusses the rationale for the prototype engine's design power output and the consequent sizing of the engine, together with providing some details of its performance on 95 RON unleaded gasoline (ULG).

The Concept

At the outset of the programme, consideration was given to defining the power range of the engine. Lotus believes that while it is thermodynamically desirable to target a single operating point for a range extender, provision of a range of power output is in fact very important for practical vehicle operation. Central to the decision process are two considerations: the drive cycle it is to be assessed on and the desired depleted-battery maximum speed of the vehicle. The former helps to set the minimum power insofar as it must effectively be above this level. In fact, it may be desirable that it be lower for protracted use in cities where the average power can be very low. Hotel loads will clearly cause this end of the operating range to increase, but since the legislated drive cycles do not include a requirement to support high hotel loads these are less of an issue at this end of the power range. The depleted-battery maximum speed of the vehicle effectively sets the maximum power output; here practical levels of hotel load need to be taken into account as they will reduce the power available for vehicle propulsion. Within these limits it is desirable that the brake specific fuel consumption (BSFC) curve of the engine be as flat as possible, since it is envisaged that the engine be capable of operating continuously at any power output between these speeds; this is so that the amount of power being diverted to the battery is as low as possible in normal use, with the bulk preferentially going to the wheels to minimise round-trip losses via that route.

The power limits for the Lotus Range Extender were determined by modelling to the above approach and set to be 15kW and 38kW at each end. With a target of just under 11bar brake mean effective pressure (BMEP) and an initial maximum engine speed of 3500rpm, this effectively set the engine's swept volume of 1.2ltr. Its 3-cylinder configuration was selected after an exhaustive parametric study concerning combustion efficiency, package, noise, vibration and harshness, cost and the ability to spin-off future variants and power outputs. Generally, low mass and good NVH would be desired over ultimate efficiency, since the engine has to be carried all the time and, for most customers, would spend most of the time as a dead weight in the vehicle reducing its electric-only range. Nevertheless, having arrived at a format satisfying the first two, the best efficiency then possible is desirable. Following this logic, essentially the most attractive competing configurations were in-line 2- and 3-cylinder layouts; the triple was selected for reasons of future potential cost down (it being possible to imagine deleting the balance shaft in this configuration and not the twin) and knock control with

Fig 1: Photograph of assembled engine from the exhaust side, showing monoblock construction and IEM

the new, two-valve-per-cylinder combustion system especially developed for the engine.

The combination of a two-valve-per-cylinder combustion system and just under 11bar BMEP at low speed set a severe target for the combustion development team, made more challenging by the requirement that this be achieved when operating at stoichiometric conditions on 95RON ULG and be knock-free at maximum power. The adoption of the monoblock configuration was a major contributor to achieving this, as will be discussed later.

Two-valves-per-cylinder and a belt-driven single overhead camshaft (SOHC) were selected, driven by cost and friction considerations. Pushrod valve operation was considered in the interests of package size but an assessment concluded that, in a single-bank engine, a simple SOHC configuration would be cheaper with less friction (and only slight demerit in height). Port fuel injection was also chosen for similar reasons as well as good mixture preparation.

The combustion chamber itself is a modified bathtub with slant squish and this and the small bore (and consequently undersquare dimensions of 75mm x 90mm) are all part of a package of measures to mitigate knock. The small bore is made possible by the low maximum power output. This keeps the valve sizes small and consequently the gas velocities high to the benefit of air motion in the combustion chamber; small valves also permit the spark plug to be positioned as close as is practicable to the centre of the combustion chamber in the interests of ensuring a short flame path. Extensive use was made of CFD in order to achieve the turbulence target set in order to ensure fast combustion and hence extend the knock limit. The results of this rigour are such that 10.5bar BMEP can already be achieved at 3500rpm with stoichiometric fuelling at 10:1 compression ratio, thus providing excellent fuel economy while allowing simple and robust exhaust gas aftertreatment.

In addition to 95RON ULG, the engine can also operate on ethanol and methanol and any mixture of the three.

The achievement of the ambitious combustion targets was aided greatly by the adoption of monoblock construction, combining the cylinder head and block in a single casting, thus eliminating cylinder head bolts and head gasket. It is accepted that the resulting monoblock casting is complex but overall there is a slight reduction in the number of casting cores compared to a conventional approach and a significant reduction in the total number of machining operations. Honing a blind bore and machining the valve seats are not significant issues. While a significant number of components are therefore eliminated from the engine (at the expense of a slightly more complicated main casting), an important result is that greater freedom in port configuration is also afforded. Indeed, the inlet port occupies an area which would have had a cylinder head bolt passing through it in a conventional architecture. The vertical valve configuration of the two-valve-per-cylinder layout in turn permits the use of a monoblock because it allows simple machining of the valve seats. On the exhaust side, the absence of head bolts permitted the ready adoption of an extremely compact integrated exhaust manifold (IEM) which, together with the 3-cylinder configuration, helps to extend the knock limit by ensuring that any re-ingested residuals are cooled to a greater extent than in a separate-manifold engine. The IEM also accelerates catalyst light-off while reducing mass and cost.

Figure 1 shows a photograph of the assembled engine from the exhaust side, illustrating the package potential of a well-designed monoblock and IEM and also showing the full-bolted attachment of generator to crankcase which was adopted. Note that this architecture, with its freedom from head bolt intrusion into cylinder head area real estate, is ideal for diesel engines. General specifications of the engine are given in Table 1.

General layout	1.2 litre 3-cylinder with 2 valves per cylinder, belt-driven single overhead camshaft
Construction	Monoblock with integrated exhaust manifold All aluminium Balance shaft (deletable)
Capacity	1193cc
Bore and stroke	75.0mm x 90.0mm
Compression ratio	10:1 (11:1 and higher protected for)
Maximum power (target)	38kW (51bhp) at 3500rpm (10.9bar BMEP)
Maximum engine speed	3500rpm (protection for 4000rpm)
Fuel system	Port fuel injection, Lotus EMS
Fuels	95RON ULG / ethanol / methanol
Dry weight	60kg

Table 1: Lotus Range Extender engine specifications

Achieving Performance and Efficiency

The results from the sign off test proved incredibly successful and are shown in Figure 2. Here SFC is shown as a function of engine power, which is the normal way of presenting such data in power generation; since the engine is intended to produce electrical power, this convention has been adopted

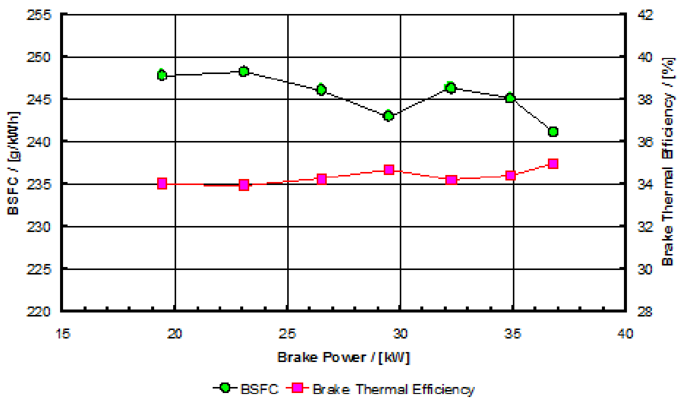


Fig. 2: Initial full-load BSFC and brake thermal efficiency versus power, Lotus Range Extender engine number 001

here. (It should be stressed that this data is based on brake power and not on electrical power.)

Immediately apparent from Figure 2 is that in this initial ‘as-tested’ form the engine almost reaches the original 38kW target and that the fuel consumption is already very good. The reported maximum power point of 36.8kW in Figure 5 corresponds to 3500rpm, meaning that the engine is generating 100Nm at this point and operating at 10.5bar BMEP, just at the knock limit on the 95RON fuel being used. For a two-valve combustion system operating without power enrichment (i.e. at Lambda = 1) this is considered to be very good indeed, and coupled with the fact that 95 RON gasoline was being used the maximum power BSFC of 241g/kWh is outstanding, representing as it does 35% thermal efficiency. It should be noted that while direct-injection spark-ignition engines with turbocharging and dual cam phasing devices can deliver this level of efficiency at or near to peak torque, they cannot do so at their maximum power point, where what is believed to be the best currently reported for this condition is 270g/kWh (without cooled EGR).

The friction MEP is at a low level of approximately 0.6 bar throughout the power curve, meaning that the aim of realising very low friction has been achieved. The mechanical efficiency at full load is 90-92%, which is extremely good for a naturally-aspirated 4-stroke engine.

Since the engine becomes steadily more knock-limited below maximum power there appears to be some opportunity to balance some throttling loss against combustion phasing in future calibration work. As part of this undertaking it is planned to fully map the engine as though it were a conventional unit, and so to be able to determine the optimum locus of operation when any given generator efficiency map is applied. The proposed UQM generator for the initial application of the engine has a claimed efficiency of 93% at 37kW and 3500rpm, which implies that the electrical SFC of the combined engine-generator unit at this point will be just over 259g/kWh (with just over 32.5% thermal efficiency). Interestingly, this is still better than conventional spark-ignition engines can achieve delivering maximum power into a mechanical transmission (although it is accepted that the Lotus Range Extender engine has not been developed to deliver such high specific power at high engine speeds).

Variety of Applications

Lotus has created a dedicated range extender engine for plug-in hybrid electric vehicles, designed to automotive practices and with automotive legislation in mind. The engine has been protected to operate on gasoline, ethanol or methanol, or any ternary blend of the three.

Cost and mass have been addressed by adopting monoblock construction with an integrated exhaust manifold, itself permitted by the adoption of a two-valve-per-cylinder combustion system with vertical valves. The dry engine mass is 60kg and performance is on track to meet the 38kW target with a BSFC of 241g/kWh. Both of these will improve if the balance shaft is removed.

The combustion system was developed to have a good knock limit, achieved through the adoption of high turbulence, small bore, near-centrally-mounted spark plug and slant-squish combustion chamber geometry. As a consequence the engine operates knock-free at maximum power when operating on 95 RON fuel.

Low friction has been achieved with a high mechanical efficiency of 92%.

The monoblock architecture would readily suit other engine types; in particular, the diesel engine, with its premium of cylinder head space and challenge of head gasket durability, would seem to be an obvious candidate for the approach.

Source: Jamie Turner, Chief Engineer of Powertrain Research, Lotus Engineering

Supplier Focus: Evo Electric Limited

In Supplier Focus we take a look at one of the many organisations Lotus works with on a project collaboration.

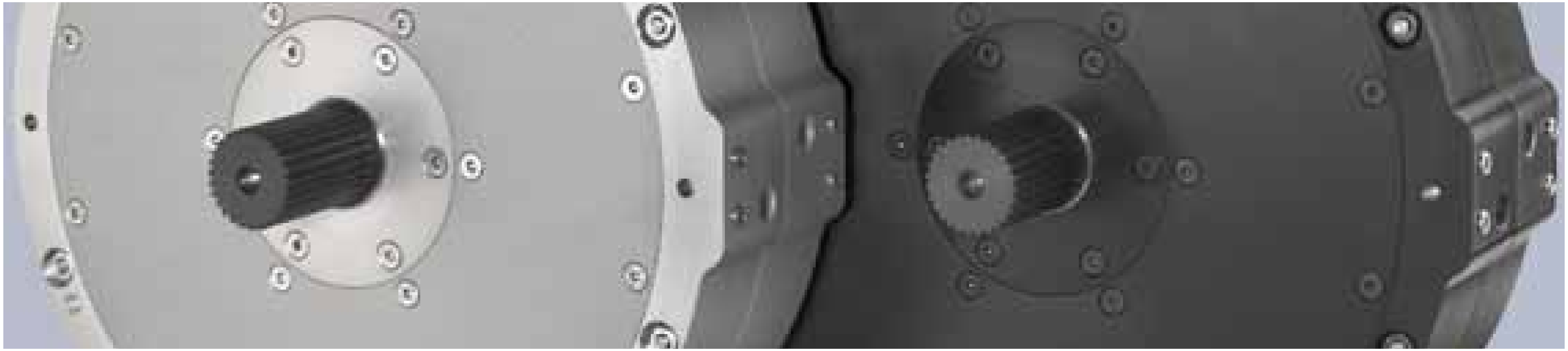
EVO Electric Limited was established in June 2007 to commercialise a new design of 'Axial Flux' permanent magnet synchronous AC machines, developed at Imperial College, London by Dr Michael Lampérth. Axial Flux makes greater use of the available space for electromagnetic interaction, resulting in much higher torque and power densities than conventional machines. This is especially true if the available space to fit the machine has a larger diameter than length. Another way of understanding the benefits of axial flux technology is using the analogy of disk brakes which have a similar geometry to axial flux, and drum brakes, which are similar to conventional motors in their geometry.

EVO electric is not the first company to produce axial flux machines as the benefits of axial flux have been known for a long time; however it was not possible to build machines that lived up to expectations and this is where EVO electric comes in. Utilising innovative materials, thermal design and manufacturing techniques, EVO has successfully developed a high-power and robust design suitable for automotive applications.

The ultra light and compact EVO design also allows for very high peak torque (e.g. the 380mm diameter/40.2kg model produces 600Nm for 18 seconds), eliminating the need for gearboxes in many applications. What is more, the short axial length and flat mounting faces make the machine very suitable for direct mounting onto a combustion engine or use on machines for direct drive motors in cars. Should the available torque or power not be enough, then two machines can be packaged together resulting in a doubling of the output. To allow for application of EVO technology, where the available diameter is smaller, EVO designed a new range of machines with 300mm diameter. The debut of these machines is on the Lotus Evora 414E Hybrid Concept.

Last but not least, EVO motor/generators are competitively priced due to the inherently low material costs of Axial Flux designs as well as proprietary manufacturing techniques. Combined with the compact size and high torque of EVO motor/generators, this can dramatically reduce hybrid and electric vehicle development costs by eliminating the need for major powertrain redesign. The company thus offers OEMs a low-cost route to drivetrain electrification and hybridisation, and the most realistic path for fuel economy improvement and CO_2 reduction.

Source: Evo Electric



Hybrid and electric vehicle testing at Lotus

Driven by the increasingly stringent government regulations and energy security concerns, plus higher oil prices, virtually all leading car makers are exploring ways to reduce their vehicles' carbon dioxide emissions and increase their fuel efficiency. These forces are driving the development of alternative concepts for automotive propulsion as well as alternative fuels. To meet this challenge, the automotive industry is investing large R&D budgets in a variety of new technologies for automotive propulsion.

With the recent progress in electric and hybrid vehicle development (EV and HEV), and the expected increase in series hybrids and pure EV's in the market place over the next ten years (Fig 2), the maximum energy density, currently at 170Wh/kg, is expected to increase to 270Wh/kg in the same timescale. It is therefore imperative that OEMs test and develop motor/inverter efficiency and power management strategies and there is an understanding where the inefficiencies are in electric vehicle powertrains, which, in turn, will help OEMs to meet the demands for greater range.

Currently there are no drive cycles specifically for EV's thus the automotive industry tests that have been globally accepted are those of combustion engine test schedules, i.e. NEDC/ FTP/FUDS etc. Results from these tests will correlate fuel efficiency, reduced CO_2 emissions for hybrid vehicles and range comparisons for pure EVs. It is important that the industry establishes a drive cycle specifically for EVs so that buyers are confident it represents real world use.

Drive system performance is an essential part of the electric vehicle. The drive system is the link between the energy stored in the batteries and the transfer of this energy to the road. A high efficiency drive system can best utilise the batteries and effectively increase the range of an EV and ultimately, the cost of owning one. Therefore, accurate measurement of drive system efficiency is a primary concern for the EV drive system designer. The most productive route to achieve repeatable and accurate results and reduce development hardware-in-loop testing. This method negates the use of extensive mule vehicle tests either on the rolling road or test track, plus can have the added advantage of testing in parallel to vehicle build. Electric vehicles also have a limited on board energy storage system (battery), which depletes very quickly under high load testing. The time required to recharge the high voltage battery depends on the kWh of the battery pack but on average via a domestic supply it would be a minimum of five hours. Therefore a facility to emulate the vehicle's energy storage system during testing becomes advantageous.

The hybrid fuel cell taxi project currently underway at Lotus is using such a system. Lotus has designed and commissioned its EV test cell to perform hardware-in-loop testing of the whole hybrid drivetrain. The test bed consists of a Froude Texcel V6 Digital controlled dynamometer connected to a Yokogawa WT3000 power analyser and other data collection tools.

The illustration (Fig3) shows the test cell configuration to test and validate the power management of the fuel cell/battery vehicle.

The test bed design incorporates power sharing between the two voltage sources (battery and fuel cell), using high voltage DC power supply units (PSU).

The Lotus Engineering HEV Test Cell

Two 32kW Regatron regulated and fully controllable DC power supplies for EV and HEV subsystem testing to simulate the battery and fuel cell. Both the current and voltage values are programmable and the units are capable of simulating the discharge characteristics of a battery pack. If used in conjunction with a regenerative module, the units can be used to perform battery cycling tests and function as a battery module for durability testing of other EV and HEV electrical components. The units are based on a modular concept ensuring systems can be easily expanded as power needs dictate.

The 32kW PSU designated as the fuel cell simulator is an ideal match for the specified vehicle fuel cell which has a maximum output of 30kW. Although the maximum current output of the PPSU (80A) is

Hybrid and electric vehicle testing at Lotus

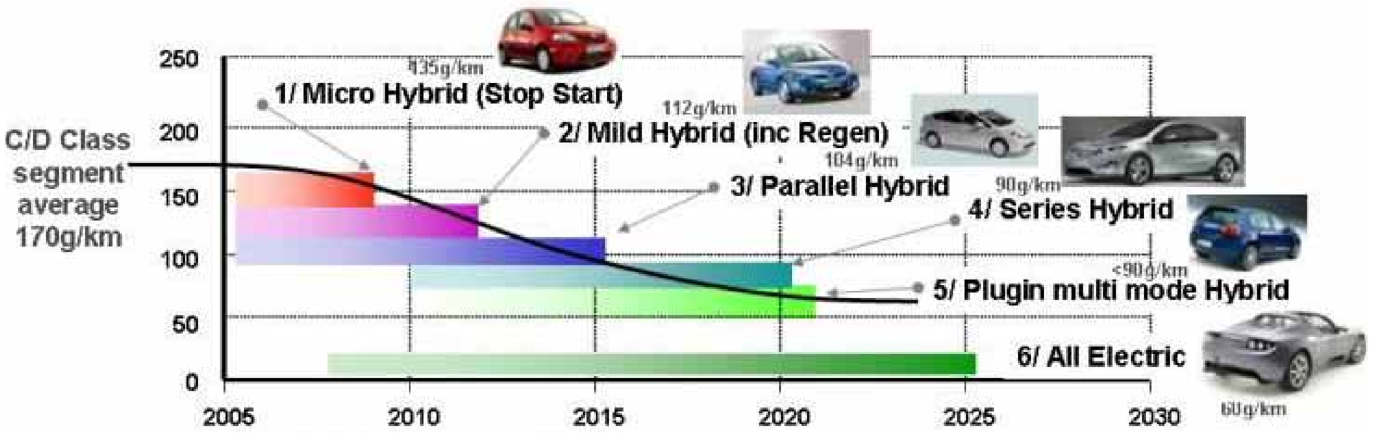


Figure 2: Vehicle hybridisation trends

less than the fuel cells 150A, the PSU emulates the fuel cells optimum efficiency. The 64kW of combined power is enough to develop the control strategy for the high Voltage DC/DC converter (power sharing device under test).

For high current/torque demand and peak power testing, the test cell was designed to be able to accept the vehicle 14kWh battery pack alongside the fuel cell DC PSU.

The high-voltage distribution box is spilt into two independent supplies to replicate the fuel cell and battery supplies.

For the fuel cell taxi project, the objective of the testing programme was to develop the software control strategy for the high-voltage DC to DC converter. This involved mapping the voltage and current under different load settings for the converter to manage the power sharing of the two voltage sources (battery and fuel cell). This calibrated model will then be installed into the Lotus Hybrid Controller (LHC), which controls the power management of the hydrogen fuel cell vehicle.

Subsequently, the test cell was also used to dynamically test the Lotus Hybrid Controller, simulating vehicle operation encompassing throttle control, power sharing control, voltage and current measuring. A Lotus-designed general purpose module was used to measure the battery and fuel cell voltages and currents. This information was transmitted to the hybrid controller using a PWM output. This multi-purpose module is also used elsewhere on the vehicle, utilised as a safety controller with sensor inputs to detect hydrogen leaks, as well as driver and passenger interface displays.

As stated earlier, the test cell was primarily designed to develop the power sharing concept from the dual voltage sources, but it can be easily adapted to supply 64kW of total power by connecting the DC PSUs in parallel. Additional power supplies can be installed to increase the specification of the total power available to 256kW.

Currently, to enable peak power testing of the motor, the electric vehicle battery pack is installed into the test cell and used as the primary voltage source. Because a battery can absorb current as well as supply it, this dynamometer can effectively test all four quadrants of motor operation. A 15kW AC motor was coupled to the rear of the dynamometer via a one-way clutch to enable regenerative brake testing.

The combination of tools for steady state and drive cycle tests offers a complete platform for testing and characterising electric vehicle drive systems. Data acquisition brings all the data together and data analysis offers insight into the best interpretation of the data to best judge the efficiency of the motor/inverter and drivetrain. Lotus Engineering has made significant developments over the past 20 years in the area of hybrid and electric vehicle technologies and continues to increase the amount of consultancy work in this field. With this technical expertise and the advanced testing facilities, it adds to the portfolio of products and services that Lotus Engineering offer its extensive clients list.

Source: Gary Spinks, Powertrain Testing, Lotus Engineering

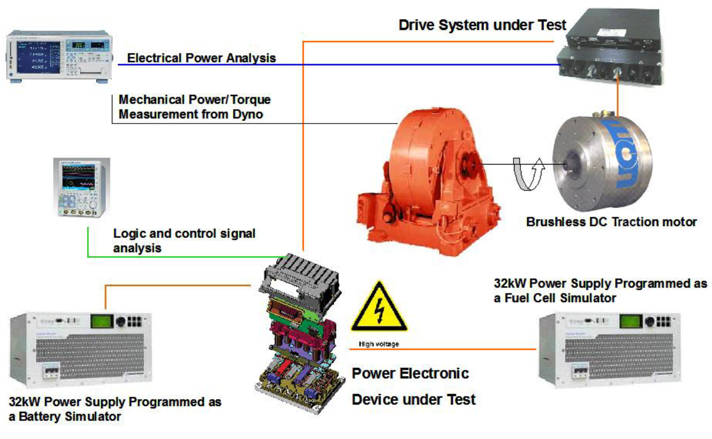


Figure 3 :Test Cell configuration

Q&A with Richard Parry-Jones: Part 2

This interview continues from the last issue of proActive.

DL: What's your view on electric drive and electric vehicles?

RP-J: It is obviously an important area for the future. But I think we have to distinguish very strongly between hybrids and electric cars – they are fundamentally different things. Many people think they are two varieties of the same species, but they are actually completely different species.

A hybrid car still uses, exclusively, fossil fuels for its energy source and it is using the medium of electricity to find better ways of harnessing all of the energy from that fossil fuel that it receives in the fuel tank.

Electric cars, on the other hand, are a different species because they are trying to replace fossil fuel burned in the car with electricity and a different primary energy source. Electric energy, unlike petrol, is not a primary energy source, It doesn't exist in nature. It is a medium that is used to transport and store energy that is generated from a primary source, such as fossil fuels, nuclear power, or wind, hydro and solar energy. In the short term, one could be cynical and just say, well that's just burning fossil fuels somewhere else, so there is an energy generating infrastructure issue. Until the grid becomes much more powered by renewables and/or nuclear, then the environmental benefits of electric cars are very questionable.

The Tesla roadster is a fully electric car

And yet electric cars are very expensive and come with severe range limitations. Their short-term prospects are driven, almost exclusively, by a mixture of government incentives and policy, and the marketing efforts by car companies – the EV leaders wanting to be seen as progressive and to be joining the trend or fashion.

However, if we are going to get emissions from motor transport down to about 20% of their current levels, then the average ICE car is important. If the average is say 140g/km of CO_2, I believe we can get that down to 70g/km, maybe even 60g/km. But we need to get under 40g/km and I don't see how we can get to that relying only on fossil fuels. We are going to have to find a different energy source and there are only really three candidates: biofuels, hydrogen and electricity. The last two are not pure energy sources, they are energy transport mediums and not freely available in nature. So you have to find a primary energy source – nuclear or renewables – and then decide, do I use that to generate hydrogen as a transport medium or electricity as a transport medium?

I am somewhat sceptical about hydrogen as a sensible transport medium for energy created through nuclear or renewables. My money is on electricity.

I think in the long haul – and by that I mean 2030 not 2020 – I think we will have to see the mass market for electric vehicles develop. Hopefully by then, as result of massive investment in battery technology and so on, we will have vastly improved the range but I do not believe we will ever match the range of the current liquid fossil or biofuels vehicles. The challenges are huge – battery materials are not abundant and recycling technology has much further to go

I think that even in 2030 there will be a sizeable section of the vehicle market that will be powered partly by electricity and partly by biofuel – and these are the so-called plug-in hybrids. But these vehicles will struggle to do well in the current market without significant government incentives because it is so expensive and what are the incentives for customers?

DL: What about the argument on the production economics that says when take up is large enough unit costs will fall dramatically?

RP-J: No, that won't do it. The fundamental technology is more expensive than what we have now. This is not simply a scale and learning issue. Scale and learning will reduce the cost of batteries by another half. That will take them down from US$6,000 to US$3,000.

DL: You are saying that battery technology is inherently very expensive and there is not much we can do about that?

RP-J: I'm afraid so. I wish that was not the case. I have heard people say, 'we are in the early phases and it will get a lot better', but people have been working on batteries for around 100 years. They will continue to improve but for it to be very different we need something spectacular which, if you look at the basic physics, is probably just not do-able, in terms of making them as cheap as today's cars. They will remain significantly more expensive than today's cars.

Of course, making them affordable is the job of the industry, but it is going to take a lot longer than five or ten years.

DL: So there is a need for realism?

RP-J: Yes. Look, I am a fan of electric cars and I like driving good ones. But I fear that they are being over-hyped. I would hate to see electric cars over-hyped and then for the market to be disillusioned with them when, in fact, we are going to need them in significant scale and volume in 10-15 years' time. I am very keen that we don't destroy their development now by overplaying their current capabilities.

DL: And you see a significant role for second generation biofuels?

RP-J: Certainly, and they will become more competitive as the price of fossil fuels rises. They also have the advantage of being the most compatible alternative to fossil-fuels with the present fleet and infrastructure, so carbon benefits are potentially realised faster. But there will be tremendous competition for the use of biofuels, for example from the aviation sector. So, yes, a role for them in motor transport, but they are not a panacea. Electricity is I believe the most likely primary replacement energy medium, with biofuels as a supplementary replacement

Market mechanisms will likely direct biofuels towards situations where electricity won't work – such as aircraft and long-range car journeys, not forgetting heavy goods vehicles, too.

DL: You are co-chairing the UK government's 'Automotive Council'. How does that work?

RP-J: A look at history shows that our industrial competitor countries have successfully employed a more strategically collaborative approach between manufacturing industry and government than has been the case in Britain. The UK government's approach in the past has tended to be characterised by emphasis on moving away from being a nation that designs and manufactures things, to a service economy with financial services in the City figuring prominently in the thinking. Attitudes to manufacturing, and the auto industry in particular, have been 'laissez-faire' until a disastrous headline looms, say caused by the possible closure of a plant. In these cases we are thrown into panic mode. Depending on the government of the time, we either say it's all hopeless and the patient is dead, let's perform the last rites, or we throw billions of pounds at it in a fruitless attempt to resuscitate a patient that is already clinically dead.

What we need is a preventative approach, where we are working together to promote good health. We think that is a lower cost approach and one that is far more likely to lead to more sustainable employment and economic contribution from the industry.

We have convinced the UK government, I think, that you can't really have a manufacturing sector unless you have a viable automotive industry because of the scale

Electric cars may be greener, but the power to charge them has to come from somewhere

and innovation that the automotive sector encourages for manufacturing generally. Automotive embraces all of the important elements in manufacturing – manufacturing itself, joinings, stamping, pressing, forming, forging, casting, machining, logistics, assembly.

Most of the innovation in manufacturing has come out of the automotive sector, starting with the moving assembly line right the way through to lean production. Global competition has forced massive innovation in the automotive industry, historically.

We think it is really important for the government to proactively support the auto industry if it wants a viable manufacturing strategy.

Q&A with Richard Parry-Jones: Part 2

What we are not looking for is huge handouts and big subsidies to broken companies. That doesn't work and is a waste of money.

We are looking, first of all, for a change of rhetoric. If you are a foreign investor in the manufacturing sector, what you want to read in your newspaper is not that the British government believes that manufacturing is a no-hoper in the UK. That won't encourage you to invest in Britain. A more positive message would be that the British government believes that manufacturing is part of the modern knowledge economy, that it happens to make things using smart people and smart technologies. Most people have got a very outdated image of what a manufacturing plant looks like.

And when the tone from the top and government changes, we can attract more young people to manufacturing.

The second thing is that the government has to stop being anti-car. There has been a lot of anti-car sentiment coming from government driven by what I call 'the south-east effect'. It all looks feasible from London to replace the car with some other form of mass transportation but it just doesn't work outside London.

We are saying, very simply, 'please work with us.' Cars are not going to go away in a modern transportation system, so let's work together on all the things that need to be done, in a joined up way, to get the best outcomes from an economic and sustainability perspective.

DL: So there's that high-level strategic picture that involves talking to government about policy and how the industry moves forward. Is there a specific R&D aspect, too?

RP-J: Yes, at a lower level there are more specific interventions to ensure that the money that the government does spend to encourage R&D is spent in the right areas. The whole idea is to get everyone together and coordinating properly.

DL: And you expect the work of the Automotive Council to continue even if there is a change of government in Britain this year?

RP-J: Yes, we have had assurances from the opposition that they broadly support the work that we are doing. There may be some differences in emphasis but I am confident we will have momentum that would not be stalled by a change of government – should that happen.

DL: What do you see as the big challenges for the auto industry globally?

RP-J: I think it goes beyond the CO_2 problem, which is just one of the challenges under the heading of personal mobility sustainability. We are over-dependent on imported fossil fuels, which are located largely in unstable geopolitical areas and depleting much faster than reserves. This will lead to increased price volatility caused by various political crises, and a rapidly escalating underlying trend price for oil. By the time each crisis hits us, it is far too late to respond with new technology, so we need some intelligent, technology neutral fiscal market intervention by Government, There is also recycling, longevity of product and there's the whole life impact of resource consumption in personal transportation. The auto industry has to use its brain and muscle to help figure out solutions that benefit everybody.

The problem of CO_2 is not to be underestimated, but I see it as a part of this broader sustainability question.

Just stepping back, one problem I think we have is how market mechanisms work and how we incentivise customers to favour sustainable solutions and lifestyles over less sustainable ones. The problem we have with the free market and the economics of sustainability is that the free market will not drive customer behaviour quickly enough. The risk is that by the time resources become prohibitively expensive we will be over-committed to the use of those resources and the rise in raw material and commodity prices will be so abrupt that we will undergo a period of crisis.

The winners in this industry will be the ones who invest in technology and can innovate beyond immediate pressures. Shareholders tolerance for that is notoriously weak and consumers responses are limited. This issue can be addressed by Government providing a long term stable policy of escalating carbon-based tax on fuel, to provide consumers, car companies and investors with much improved certainty about the future attractiveness of low carbon vehicle technology. Of course, the challenge for governments is how do you stay elected and still incentivise consumers to do things that are in their long-term best interests, but not always in their short-term best interests.

For example, governments feel that they don't yet have the freedom to impose swingeing carbon taxes – they simply cannot do it in democracies. If they go too far they will simply be voted out. They have to educate the

Q&A with Richard Parry-Jones: Part 2

Public transport is a feasible option for some in urban areas

voters and we have to educate consumers on what is in their best interests. That's why it has to be done gradually, over a sustained period of time, so that customers and business has a chance to adapt and adopt new technologies, without causing hardship.

Maybe we have come full circle now, and perhaps you can see why I am spending a third of my working time on policy development – things that I know the industry on its own can't fix.

DL: Are you optimistic about the future for the auto industry?

RP-J: Yes, for two reasons. One is that I think that having invented personal transportation, it is such a fantastic thing for humankind that I cannot conceive of a situation where humankind will forego it without huge resistance. And on the contrary, what we are seeing is developing countries embracing it.

And I'm optimistic about the sustainability aspect because I really believe in how smart we are as engineers. If you look at what we have achieved in the last 100 years without anything like the same pressures on sustainability that we are facing for the next 100 years, I'm incredibly optimistic about the ability of engineers to find ways of reconciling apparently conflicting requirements. It is what engineers do best.

DL: Thanks Richard. Before you go, can I just ask you what you are driving these days?

RP-J: Well, apart from my bicycles – and I am a big fan of the Brompton fold-up bike, best way to get around central London. My daily transport in Wales, where I live, is a Focus. My workhorse is a diesel Range Rover which I use for my outdoor sports and transport needs. It is useful for towing – my partner is an equestrian, so we tow horseboxes, as well as boats. The Range Rover is the ultimate Swiss army knife vehicle. I also have in the garage an Aston V8 Vantage for fun drives on summer Sunday mornings.

Source: just–auto.com editorial team

Richard Parry-Jones

Richard is an automotive engineering leader who worked for the Ford Motor Company for 38 years between 1969 and 2007. Until his retirement from Ford at the end of 2007, he spent nearly ten years as Group Vice-President in charge of R&D for all of Ford and its subsidiary companies worldwide, leading a staff of 30,000 professionals in a network of Product Development centres in 15 countries. He was also the Company's Chief Technical Officer for the last 8 years.

Richard is now working on a variety of projects, having formed an engineering consultancy company with a blue chip client portfolio. He also holds a number of non-executive directorships, and works on governance with several Universities (Loughborough, Cambridge, Warwick Business School) He chairs the Welsh Assembly Government Advisory Group for developing policy on Economic Growth, Transport and Energy, and was recently appointed Chair of Automotive Industry Growth Team for the UK Government.

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For more information, feedback or other enquiries please contact:

Lotus Engineering
Hethel
Norwich
Norfolk
NR14 8EZ
United Kingdom

Editor: Peter Morgan

Website ▶
Lotus Engineering

E-mail ▶
proactive@lotuscars.co.uk