proActive
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Issue 20
May/June 2007

EVE Hybrid – ‘retro–integration’ for a viable, low CO_2 vehicle

New products, New markets = New Lotus drivers

Welcome

More wide–ranging news from the world of Lotus Engineering! Topics include an unmanned Lotus Elise, our EVE hybrid demonstrator and a discussion on methods of joining structural materials. Thank you for joining us this issue.

An unmanned Elise! The concept is fairly simple – the execution far more complex, as Simon Cobb and I describe. Briefly though, the car was built to compete in the DARPA Urban Challenge. Some of you will be familiar with the Desert Challenge held in 2005. This time Insight Racing has partnered with Lotus to compete in a city environment.

At Geneva Lotus presented the EVE Hybrid vehicle. Steve Doyle explains how various technologies have been integrated and the benefits yielded. As seems to be the trend these days, advanced hybrids often rely heavily on input from specialist companies like Lotus.

Jason Rowe discusses how Lotus is increasingly assisting manufacturers in the selection and application of new joining processes. The increased use of aluminium can only be realised if it is safely and economically joined into the structure.

I hope you find this issue interesting.

Tim Holland
Lotus Engineering, Inc.
Ann Arbor, Michigan, US

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Tim Holland

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UK: Hybrid sales double in a year

Sales of hybrid cars in the UK have doubled in the last 12 months making cleaner cars the fastest growing sector in the industry, according to Honda.

Year–to–date hybrid sales rose 111% from 3,117 to 6,568 cars.

Honda UK sold a record 604 Civic Hybrid sedans in May, bringing year–to–date sales to 1,136.

Increased corporate sales, as an increasing number of public and private companies recognise the financial and environmental benefits of running hybrid cars, contributed to the result, Honda said.

City Car Club, a 'pay as you go' car–sharing scheme based in the London borough of Camden, has ordered 45 of the petrol–electric Hondas for its clients to use.

Source: just–auto.com editorial team

MEXICO: Chrysler to build new engine plant

Chrysler is to spend US$570m on a new engine plant in Saltillo, Mexico.

Scheduled to begin production in 2009, the plant will produce the new Phoenix family of fuel–efficient V6 engines.

Plant construction begins in June 2008.

The Saltillo plant is part of Chrysler's US$3bn so–called 'powertrain offensive' announced in February for the production of more fuel–efficient engines, axles and transmissions.

The Mexico plant is the second Phoenix engine plant recently announced by the automaker. The other will be in Trenton, Michigan, next to the current engine site.

"The Chrysler Group has a deep commitment to our Mexican operations with more than 60 years of history here, and we will continue that commitment going forward," a spokesman said.

The new plant will have an annual manufacturing capacity of 440,000 engines and will be situated in Derramadero, near Chrysler's Saltillo truck assembly plant, which builds the Dodge Ram.

Once fully operational the plant will have 485 full–time employees.

JAPAN: Miller cycle engine improves Mazda economy

Mazda has developed a new, naturally aspirated MZR 1.3L Miller–cycle engine for the redesigned Demio (exported as the Mazda 2) which goes on sale in Japan in July 2007. The engine delivers up to a 20% reduction in fuel consumption.

Combined with the automaker's first continuously variable transmission (CVT), the new engine can achieve fuel economy of 23.0km/litre, an improvement of approximately 20% over the 19.2km/l rating of the current model.

Developed from the current MZR 1.3L DOHC aluminium engine, the naturally–aspirated Miller–cycle engine employs delayed closing of the intake valves in order to reduce pumping losses and improve thermal efficiency through a higher expansion ratio.

Intake valve timing is optimised by a sequential valve timing system to provide improved fuel efficiency over the current MZR 1.3L engine when cruising and accelerating.

Mazda said the combination of the engine with the CVT allows the transfer of torque at low speeds without power loss and eliminates gear–shift shock, achieving excellent fuel efficiency and a smooth ride.

Reducing the weight of the redesigned Demio by 100kg has also helped improve fuel economy.

The new car achieves a fuel economy that is rated as 20% better than the level specified by Japan's 2010 fuel economy standards.

Exhaust emissions are also at least 75% lower than 2005 standards, and conform to Japan's Super Ultra–Low Emissions Vehicle (SU–LEV) standard, qualifying the latest Demio for 'green tax' exemptions.

Source: just–auto.com editorial team

Demio production started in Japan for a July domestic launch.

FRANCE: Renault reworks Laguna

Renault has revealed more details of its redesigned European D–segment Laguna which competes with the likes of Ford's Mondeo, Toyota's Avensis and Peugeot's 407 in the sub–luxury segment.

There's a lot of new model activity here just now – Ford is rolling out the redesigned Mondeo and GM Europe has a new Vectra on the way.

Renault has re–done the Laguna's body and interior, and upgraded the suspension while retaining proven engines that have mostly been renewed in the last few years.

The new model has closer–ratio steering and uprated suspension while, according to the French automaker, "significant work has also gone into the tuning of its damping performance to ensure even greater driving pleasure and comfort".

Powertrains again major on diesels including 130 and 175hp versions of the 2.0 dCi unit which can also be mated to automatic transmission, a combination growing in popularity in Europe.

Best performer, environment–wise, is the 110hp/81kW 1.5 dCi which sips as little as 5.1 litres/100km and emits 136g of CO_2 per kilometre.

Petrol engine options include the jointly developed Renault/Nissan 145hp (103.4kW) 2.0 16V unit.

Safety equipment includes a claimed exclusive new–generation double lateral airbag (thorax + pelvis) which is based on a twin–chamber, dual pressure system triggered by two sensors located in the front door and B–pillar.

A specific algorithm adjusts the system's deployment time as a function of the force of the impact.

The reworked Renault Laguna's interior

The new–look Renault Laguna exterior front and back

Also new is an externally–controlled, high capacity air conditioner compressor that is capable of producing cold air particularly quickly.

Other new features include electronic parking brake, a centre console–mounted multi–media control and, for the wagon, a system that allows a flat load area–floor to be obtained at the push of a button.

Renault is stressing improved quality and reliability for its redesigned Laguna and said its target is for the new model to rank among the top three cars in its segment in terms of product and service quality. In addition to more stringent design and production processes that have been put into place, more than 120 new Lagunas were subjected to the equivalent of 6m km of testing.

The updated line will be displayed at September's Frankfurt motor show and goes on sale from October.

Source: just–auto.com editorial team

New products, New markets = New Lotus drivers

As we head into the Northern Hemisphere's summer, there are a number of drivers who will be giving their track day pride and joys a final polish before heading out to the thousands of circuits around the world.

Leading the track day warriors out onto the grid, the Lotus 2–Eleven goes on sale shortly. Prior to the customers driving the latest Lotus stablemate, our dealer network and the press donned crash helmets, fastened the seat harnesses and whizzed around the Hethel test track – whiz is the correct adjective as 0–160km/h (0–100mph) in less than nine seconds is serious performance. Especially when the car is road legal – in certain territories of course.

The verdict from the press? Have a look for yourself: *The Sunday Times* said "I have found a new way to have fun in a car and all you need is the £39,995 Lotus is asking for its new 2–Eleven and a long straight road."

Or *Motor Trend* which said "In a closed–cockpit road–based supercar, be it 911 or Corvette or Ferrari, you operate the controls from a relatively placid environment. And as those road cars weigh at least twice as much, so they simply can't take the kind of rapid direction–changes this Lotus thrives on. "

Lotus in Thailand

Lotus Cars was pleased to announce recently the appointment of Niche Cars Co, Ltd for the retail of Lotus cars in Thailand. With the appointment of Niche Cars as an official Lotus dealer, Lotus is demonstrating its commitment to the Thai market and to true sportscar enthusiasts in the region.

Mike Kimberley, CEO of Group Lotus plc, said: "I would like to welcome Niche Cars to the Lotus family and brand. The Thai market is important to us and we are pleased to have teamed up with such an enthusiastic and professional organisation which has so much knowledge and understanding of what Lotus is all about."

The launch event for the Lotus brand in Thailand took place in April at Siam Paragon Shopping Complex in Bangkok and included a fashion display by prominent international couture labels, models and celebrities, as well as a vehicle display for potential customers and the press.

Alastair Florance

The Lotus 2–Eleven – for track day warriors

The launch of the Lotus brand in Thailand – Siam Paragon Shopping Complex in Bangkok

Lighter, safer vehicles – the role of metallic materials and joining technologies

Globally, the challenge for the automotive industry is to increase the fuel efficiency of vehicles, whilst improving safety, performance and maintaining affordability. Recent and future developments in metallic materials and associated processes have a significant role to play in achieving these objectives.

Over recent years, both the steel and aluminium industries have recognised the importance of meeting the increased demands placed on automotive materials. This has led to the development of many new material types targeted specifically at the automotive sector. The metallurgy of such materials is often complex, and the materials themselves range from advanced high–strength steels for improved crash energy management, to bake–hardenable aluminium skin materials for improved dent resistance in body panels.

Lotus has the knowledge and experience to select the optimum material grade and associated process for a particular application, and to ensure manufacturing feasibility of all metallic components. This has been demonstrated over a variety of projects, both for Lotus cars and for clients which have optimised the use of some of the latest steel and aluminium materials, process technologies, and simulation software available to the industry.

Figure 1: Crushed aluminium extrusion

One example of material optimisation is the extruded aluminium crush cans used on Lotus versatile vehicle architecture (VVA) structure, which utilise a 6xxx series alloy with a specific heat treatment cycle. The metallurgy of this material has been developed to absorb higher levels of energy with improved crash performance. The structure/property relationship enables the material to crush without fracture as can be seen in Figure 1. The use of extrusions for this type of application enables the application of high–strength alloy materials compared to pressed sheet grades. This particular alloy is air–quenched which reduces component distortion and assists with achieving targeted dimensional tolerance requirements. Weight reduction is also possible for this application due to gauge optimisation and removal of additional joining flanges.

> *"Lotus has the knowledge and experience to select the optimum material grade and associated process for a particular application..."*

In addition to extrusion materials selection and manufacturing support, Lotus materials engineers carried out manufacturing feasibility and materials specification for approximately 280 aluminium body panels for VVA. These complex panels in the structure are produced using conventional press–forming methods and are technically demanding in terms of manufacturing feasibility. This is due to the reduced formability of aluminium compared to steel and, therefore, reduced panel draw depth. This is exacerbated by aluminium 'spring back' being twice that of steel. In order to achieve feasible panel design and reduce the risk for 'problem' parts in production, Lotus utilised 'Autoform' metal forming simulation software from the earliest stages in the design–phase. This required the input of robust materials data from suppliers combined with in–depth press tooling knowledge. This combination is critical in order to achieve meaningful results, which are fed into the engineering and design team repeatedly as the design evolves to achieve a feasible part for manufacture. Figure 2 shows a simulation model of a door ring demonstrating problem areas requiring design changes.

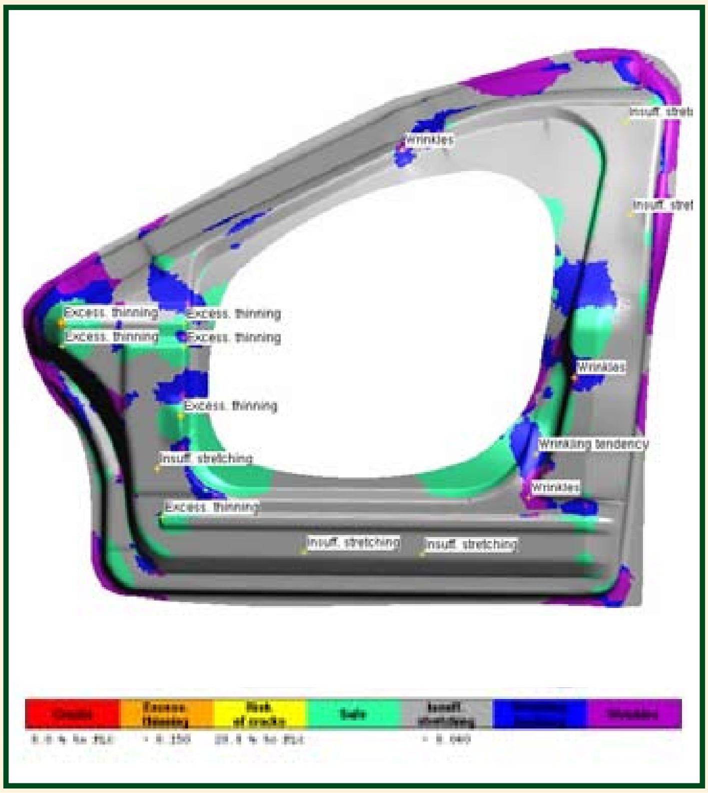


Figure 2: Autoform simulation of a door ring

This iterative process has now been used on a number of vehicle projects at Lotus with excellent results, exemplified by the VVA prototype panels, produced with few difficulties to a high quality.

In addition to pressed and extruded components the VVA structure utilises 12 high–pressure die castings including structural corner nodes. High–pressure die castings were used to achieve thin sections (minimum wall thickness around 2mm) and large surface areas whilst maintaining high levels of elongation. The castings were used to give improved body and point stiffness, dimensional tolerances, part integration and reduced tooling investment. In addition, the high pressure die castings are exploited for use in crush zones of the body structure in certain instances.

A future trend for metallic materials within the automotive sector is undoubtedly for lighter–weight materials at lower cost. Such examples include die–cast magnesium for inner body panels and hot formed magnesium pressings, both of which offer significant mass–reduction benefits compared to aluminium. Whilst magnesium die castings have already been used for inner panels on some production vehicles, the mass–reduction potential comes at a price and will not be commercially viable outside of luxury and niche vehicles unless material and process cost is reduced. This can be achieved only if material, component and car producers such as Lotus work together to achieve further possible applications and increased demand.

Joining technologies

This discipline at Lotus has traditionally focused on more ‘modern’ adhesive technologies – the most notable example being the one–component heat–curing epoxy material used on the Elise aluminium chassis. However, the varied nature of client projects has required a skills–base that now includes thermal, cold and mechanical fastening techniques.

Advances in current joining technologies are being driven by the use of new, lightweight materials and hybrid structures. The use of such materials has necessitated the development of alternative joining techniques to replace the more traditional technologies such as spot welding for body manufacture. These conventional steel–welding processes are known to give rise to stresses, lowering the fatigue life of a joint and promoting stress corrosion, both which act to compromise vehicle safety.

The drive for lightweight structures leads to the requirement for lower gauge parts, whilst continuing to meet the ever–increasing durability and safety performance requirements on new vehicles.

“A future trend for metallic materials within the automotive sector is undoubtedly for lighter weight materials at lower cost”

A riv–bonded body can provide an excellent combination of light weight, high torsional stiffness and high energy absorption. The crash–stable adhesive works in harmony with the mechanical fasteners to absorb high levels of energy and minimum displacement of crush beams, increasing the potential for occupant safety in the event of dynamic impact.

In order to meet these stringent requirements it is becoming increasingly necessary to adopt a multi–joining approach to body structures, using a combination of different joining processes to meet the vehicle’s targets.

The recent trend for aluminium vehicles has driven the use of new welding techniques such as laser welding. Such techniques often do not maximise structural efficiency as a compromise needs to be made with the aluminium gauge to allow for the reduction in mechanical properties around the welded joint (known as the Heat Affected Zone).

Advanced cold joining techniques such as self–pierce riveting (SPR) and mechanical fastening techniques requiring only single–sided access permit down gauging of the aluminium materials and offer the weight savings required by manufacturers. Such techniques also allow the joining of dissimilar materials and processes, e.g. aluminium to steel or aluminium extrusions to aluminium die or sand castings. However, the use of mechanical fastening alone does not provide optimum joint performance for dynamic impact and torsional stiffness.

One of the biggest recent advances in joining technologies is in the performance of structural adhesives. The latest generation of structural adhesives has been designed to provide toughness and therefore directly contribute towards increased vehicle safety by increased energy absorption. Structural adhesives can provide excellent stiffness, strength and impact resistance and are increasingly used in primary structure applications.

Where once adhesives were considered only for niche products, they can now be found in higher volume products such as the 5 series BMW. The chemistry of the crash stable structural adhesives is suited to the conventional automotive production line. These adhesives typically cure at temperatures around 180°C and therefore the electrocoat process, a pre–treatment prior to paint, can be used to cure the structure without the need for a dedicated curing oven.

Whilst adhesives can now provide many structural advantages, there are major benefits to be had by combining this technology with a mechanical fastening technique as Lotus has done on the VVA structure. 'Riv–bonding' provides the advantages of each technology whilst at the same time eliminating some of the disadvantages. For example, the combination of SPRs and adhesive provides a joint with far greater peel resistance than bonding alone and at least three times the strength of riveting alone. In addition, the SPRs allow de–jigging of the primary structure before the adhesive is cured, holding the geometry and dimensions without specialist fixturing through electrocoat.

Lotus VVA – an example of a fully riv–bonded structure

"The automotive industry faces significant challenges in terms of legislative and product targets"

The continuing development of new lightweight and environmentally–friendly materials such as thermoplastics will drive the requirement for further advances in joining technologies. Such technologies will be required to contribute towards the customer requirement for high standards of occupant and pedestrian safety.

The automotive industry faces significant challenges in terms of legislative and product targets. The Materials Engineering department at Lotus continues to play a significant role in the application and development of metallic materials technologies and joining systems which can help to address many of these issues.

This ability has been recognised by vehicle manufacturers. Lotus is increasingly being asked to consider applications of innovative technologies where conventional pressed steel is the norm.

What we are now doing is working with other vehicle manufacturers to provide solutions that work with their existing infrastructures and to shift the mindsets of their engineers. As the message about new materials technologies and their benefits continue to filter through, the Materials Engineering team believes that significant new revenue streams will continue to be realised.

Source: Jason Rowe

What is the DARPA Urban Challenge?

What is the DARPA Urban Challenge?

Back in 2003, the US Defense Advanced Research Projects Agency (DARPA) was struggling to achieve the rate of development progress towards the Federal goal of truly autonomous or driverless military ground vehicles. DARPA decided to broaden the effort by hosting a competition in the western US desert open to any takers in 2004. The premise was for vehicles to self navigate through a marked course that included on–road and off–road surfaces using only GPS–defined waypoints and on–board sensors. To encourage the effort a prize of US$1m was offered for the first team to complete the 200 mile course in less than ten hours. 86 interested applicants submitted technical submissions for review by DARPA. A final field of 25 teams were selected to enter the race. Not a single vehicle completed the course. In fact the furthest travelled was the Carnegie Mellon University team with 7.4 miles (11.8km).

Not to be put off, DARPA repeated the challenge in 2005. The course was similar in conditions, but at 132 miles (212km) was shorter and technically more challenging with tunnels, sharper corners and a narrower course. 196 teams entered this time and these were reduced to 43 through technical assessments and site visits. Then, most critically the National Qualification Event was used to filter the field down to the final 23 entrants for the actual race. Remarkably, 22 of the finalists surpassed the previous years distance of 7.4 miles. More impressively, five teams completed the race in the allotted time. Stanford University's 'Stanley' (a modified VW Toureg) won the race in a time of just under six hours 53 minutes and in so doing netted a US$2m prize.

Into the city for 2007

Following the outstanding success of the 2005 desert Grand Challenge, DARPA needed to raise the stakes in order to accelerate progress towards achieving the Congressional Mandate that 30% of military vehicles will be autonomous by 2015. Hence, the Urban Challenge moves the autonomous vehicle race into a city environment with traffic junctions, other vehicles, and typical obstacles such as parked cars. This race is much shorter at 60 miles to be completed within six hours, but it is technically far more advanced than single vehicles following desert trials. Also, a first for this challenge, DARPA requires that the vehicles must be switchable between autonomous and human operation during the actual event.

The Urban Challenge features autonomous ground vehicles manoeuvring in a mock city environment, executing simulated military supply missions while merging into moving traffic, navigating traffic circles, negotiating busy intersections and avoiding obstacles.

The 2007 programme is conducted as a series of qualification steps leading to a competitive final event, scheduled to take place on 3 November, 2007. The exact location will be announced before the National Qualification Event in October 2007. DARPA is offering US$2m for the fastest qualifying vehicle, and US$1m and US$500,000 for second and third place.

Lotus Engineering's team in the US has long held ambitions to enter the DARPA Challenge. It embodies the rapid advance of

Lotus DARPA Elise ("Lone Wolf") prior to conversion

vehicle technologies in a competitive environment – just where Lotus thrives! A chance meeting in August 2006 in North Carolina produced the opportunity for Lotus involvement.

Insight Racing is a small team of NC State University alumni with strong technical skills in advanced computing. Founded by Grayson Randall in 2003, it has very close links to NC State University and the local IT industry. The Insight vehicle for the 2005 Grand Challenge was a 1987 Chevy Suburban converted to autonomous control for a budget of US$50,000. Insight made it through to the finals and then achieved a 12th placing out of the 196 entrants.

We met with Insight and suggested a Lotus car would be a good base for the 2007 Challenge. Being familiar with the Lotus Elise and its diminutive size, Insight politely explained about the extensive quantities of computer equipment, the stowage volume required and the heat rejection. Uncertain whether a compact sports car could work, we parted with a commitment to talk again after the team's meeting that evening. First thing next day, there was a call from Insight stating that the team wanted the challenge of downsizing the entire system and to use an Elise as their vehicle.

That was the starting point of a great team collaboration. The official launch was a press day at NC State University on

November 15, 2006 and the vehicle was named 'Lone Wolf' following a university competition.

However, there was nearly an immediate problem. The official minimum weight for vehicles entering the challenge (as sold in production form) is fixed at 2,000lbs. Low weight is a great asset of Lotus vehicles, some of which are below the the 2,000lb mark. However, in this case the donor vehicle required a hard top and this ensured that the Lotus qualified.

Then the challenge was to convert an Elise to autonomous capability – not an easy task since, as a pure sports car, the Elise has very few powered sub–systems – no power steering; no automatic transmission; just an ABS system (that would probably be difficult to access).

The conversion itself was managed at the Lotus Ann Arbor, Michigan facility. The car had to be ready by the end of January 2007. The Lotus team at Ann Arbor, consisted of Jim Christensen and his group (controls and electrical), Mike and Jim Stachowiak and team (fabrication and mechanical interfaces, engine controls/calibration), Tim Holland with a lot of help from Simon Hill remotely from the Lotus UK office.

Creating Lone Wolf

Unsurprisingly, many changes have been made to turn the standard Elise into Lone Wolf. For a driverless car that will have to move at less than 1mph in certain conditions, an automatic transmission was the only viable option. But of course the Elise does not have one. Therefore a donor transmission was obtained from a Toyota Matrix with the flexplate and torque converter mating directly to the existing 2ZZ engine. Mechanical control of the transmission is by a DC linear actuator driving the 'PRNDL selection' via cable. Electrical control to the solenoid pack is used to force the transmission into 1st or 2nd in addition to Drive in order to ensure engine speed is maintained for electrical load purposes.

For such a complicated vehicle, the electronics and electrical power supply of the vehicle have required significant modifications. Lotus customised an Automationdirect DL06 'Programmable Logic Controller' (PLC) to act as primary interface for all of the vehicle mechanical systems (steering, brakes, transmission, voltage control, emergency stops) and this directly interfaces with the modified engine control module (ECM). Communications between the control units and the Insight Racing controller hub is via ethernet.

The ECM was modified to allow the electronic throttle control to be split into two. One signal is used via the in–house designed PLC control system to command an engine speed and hence road speed. The other provides the manual throttle control when a human is actually driving. Safety limits were included for vehicle maximum speed, rate of acceleration, high idle commands (to ensure adequate electrical output) and changes to the air conditioning logic.

Providing the estimated electrical power of 1,600W is a 24V system using a modified version of the standard alternator and accessory drive with a custom–designed external regulator and voltage controller. This removed the need to use heavy, difficult–to–package batteries to compensate at low engine speeds. A crankshaft pulley change not only increased the alternator speed but has the added benefit of running the AC compressor faster.

The design goal was to develop a system that did not require any mechanical disengagement when a human operator was driving, so a toothed belt and pulley drive from a DC electric motor mounted on the dashboard was selected as the best option. This eliminated electric column assist alternatives, which would have also posed a problem for packaging. Again, the actual steering position is controlled by the PLC system (including positional feedback) which, in turn, is fed steering angle requirements from the Insight control system.

As for the brakes, these are operated by a linear actuator mounted on the floor pressing directly on the brake pedal. This allowed the human test driver to independently apply the brakes, regardless of the control system. Pedal positional feedback ensures that the necessary brake modulation is maintained.

Belt and pulley drive for steering Lone Wolf

Other vehicle modifications include a high–resolution speed sensor mounted on the front wheel hub – accurate down to 0.1mph – and the suspension springs were compressed an additional 20mm to cope with the extra mass, whilst high profile tyres further increased the ride height. This was felt necessary to minimise curb damage to the various sensors during initial testing.

You might think that air conditioning in a driverless car is surplus to requirements. However, to handle the navigation and collision avoidance Insight Racing planned to use up to nine PCs, and the trunk area behind the engine was the only logical location. So, to keep these cool the car's air conditioning was redirected from the cabin area into the trunk.

Massive computing power installed in the trunk

In order to attach the infra–red range finders and radar units, additional metal bracing was added to the front and back of the vehicle to provide mounting points. Having to support approximately 30kg of sensors at each end, the struts pass directly through the body work and attach to the chassis structure. Further modifications have been made to the clamshell to allow its removal in one piece, which is necessary for access to the engine and computers housed in the rear of the car.

The eyes of Lone Wolf – radar and infra–red

Navigating without a driver

As part of the Urban Challenge race, the Elise will get two input files from DARPA. One file will describe the system of roads and the other file will describe a *'mission'*. A mission is a series of checkpoints along the road system which the car will have to pass. Passing all the checkpoints and returning to the starting point is considered a completed mission. During the race, the teams will be given several missions to complete throughout the day. The Elise will be measured on completed missions and the time taken to complete those missions.

Since this race is in an urban environment, many conditions of city driving will be encountered. The competitors will have to follow California driving laws, pass other moving vehicles, stop at intersections, drive through parking lots, park and traverse traffic circles, in addition to other driving tasks.

To do this, the Elise uses several types of sensors to develop a 360 degree view of the environment around it. Cameras are used to determine the lane markings and edge of road. Lidars (Laser Range finders) determine the contour of the terrain, locate curbs, and find other vehicles and obstacles. Radar provides longer–range sensing of objects and helps with manoeuvring through intersections. GPS/INS Inertial navigation is used to determine the location, direction and speed while 'Attitude Heading Reference System' (AHRS) determines the attitude and yaw of the vehicle. All these combine to make complex driving decisions.

The outputs of all these sensors are fed into a series of computers which operate together to replace the brain of a human driver. Processing all this information in real time is a challenge for this type of problem. The camera image processing can take up to a few minutes to evaluate all the objects in a frame but the Elise must evaluate several frames a second run at race speeds.

Another challenge is determining what other objects are doing. For example, the Elise needs to know if the object is a moving car in its lane or a traffic cone, and everything in between. At an intersection, the control system must determine which vehicles arrived first and which has precedence to proceed through the intersection.

The sensors, although highly reliable, generate lots of raw data. All this data has to be digested and summarised for the computing brain which then makes decisions similar to a driver. These decisions include steering angle adjustment, and actual speed/direction commands which are then fed to the PLC controllers.

One unique challenge of using the Elise is miniaturising the computer resources. Where many teams are utilising large SUVs and large computing clusters, the Elise will contain 9 Mac mini computers which will be mounted in the trunk. The processes will be distributed among these mini computers and run on the Linux operating system.

> *"Since this race is in an urban environment, many conditions of city driving will be encountered."*

“Using an exciting small sports car like the Elise for the challenge has already generated much interest from the media”

Progress so far

As of late April, ‘Lone Wolf’ has completed the compulsory video of specified manoeuvres for DARPA review. It can drive itself around a course staying centered in a narrow lane, identify and pass a parked vehicle, stop at a stop line and safely drive through an intersection. Ongoing development will include incorporation of multiple sensor obstacle determination, handling complex intersection precedence, interacting with other moving vehicles, driving through unstructured areas like a parking lot and parking in a specific parking space.

Although in the relatively early stages of development, using an exciting small sport car like the Elise for the challenge has already generated much interested from the media. Already it has been filmed driving around the North Carolina State University campus for a BBC television show entitled *The Future*, to be screened worldwide this autumn and the Discovery Channel has also been filming Lone Wolf and the journey through the 2007 Urban Challenge.

Filming by the BBC for their television programme, The Future.

The Discovery Channel filming Lone Wolf and the journey through the 2007 Urban Challenge.

The Insight team have a confirmed pass through to the next stage – a DARPA site visit will take place on 28 June at Kinston Airport, North Carolina. Assuming the June site visit is a pass, the next hurdle is the National Qualification Events scheduled for October. The final event takes place on 3 November. Watch the progress on the DARPA website.

The future for Lone Wolf

All the activity with the Lone Wolf vehicle before the challenge is focused on maximising its chances of success on the day. Once the event is over however, its usefulness certainly won’t end there. Not too far in the future, it will be possible for driverless vehicles to take all the strain out of painful commutes. Whilst doing this, driver stress, accidents, congestion and emissions can potentially be reduced through technologies such as intelligent traffic systems and data sharing, proactive vehicle assistance and predictions of driver difficulties. The Lone Wolf vehicle will provide myriad opportunities to help shape these technologies of the future.

Simon Cobb and Tim Holland – Lotus Engineering US

EVE Hybrid – 'retro–integration' for a viable, low CO_2 vehicle

Increasing legislation around the world is driving advances in fuel efficiency and emissions to address the impact of the use of fossil fuels on the environment. Vehicle manufacturers face the challenge to produce vehicles with improved fuel economy that offer equivalent or even enhanced performance at a comparable cost to current models. Advanced conventional powertrain technologies continue to offer environmental improvements in both gasoline and diesel vehicles. However, these alone will not achieve desired levels of CO_2 reduction that governments are targeting. Significant reduction in vehicle weight will not be achieved for ten to 20 years due to current customer and legislative demands for safer cars, which is adding weight. Low carbon fuels (NGV/CNG/bio–fuels) are costly for global volume use and require changes in infrastructure and vehicle technology, although they will become viable in local markets where the relevant raw materials are available. Although recent advances in battery technology are bringing full electric vehicles a step closer, they too will require some infrastructure changes to provide quick charge facilities that compare with today's fuel filling stations. The promise of the hydrogen economy is some time away, due to the required changes in technology and infrastructure.

In short, technology is required which complements the evolution of conventional powertrains, while enabling further efficiency gains until a global sustainable energy infrastructure is available. Hybrid systems provide that technology 'stepping stone', building customer confidence in electric drive trains and providing a further benefit when linked to the use of alternative fuels. Today's challenge for this hybrid technology is to provide economy benefits at a low production cost.

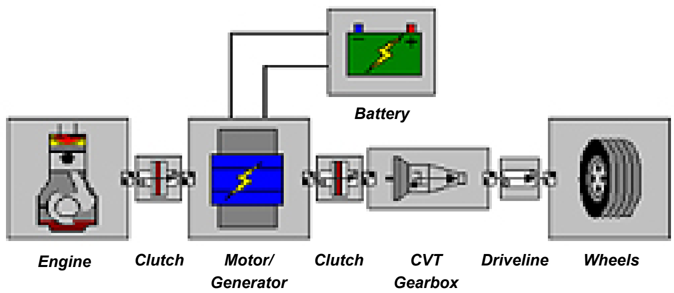
With these issues in mind, our parent company Proton approached Lotus Engineering to develop a parallel hybrid system that could be applied to a Proton Gen.2 compact midsize car with a 1.6 litre gasoline engine, with minimal impact to the base vehicle, and utilising where possible off the shelf technologies. This *'retro–integration'* approach is a key advantage of the EVE (Efficient, Viable, Environmental) Hybrid which was unveiled at the Geneva Motor Show in March. It demonstrates a realistic way for many manufacturers to develop hybrid versions of existing vehicles at much lower costs than developing whole new hybrid vehicle platforms.

Deciding on the concept

The start of the programme began with the task of carefully selecting the technologies and approach for the EVE Hybrid. A variety of hybrid systems were considered which vary in the way that the drive is combined with the conventional powertrain layout. These electric hybrids fall into distinct groups; parallel, series, multi–mode and power–split systems. The simpler forms of hybrid transmissions – series and parallel – generally offer less functionality and so reduced fuel efficiency, but are mechanically easier and cheaper to realise. Series hybrids are efficient at low vehicle speeds but less efficient on sustained high–speed cycles, and parallel systems are less suited to low speed work and more efficient at medium and high–speed driving. The multi mode and power split transmissions offer the ability to operate in series or parallel modes depending on operating conditions. Therefore they offer the greatest overall efficiency, but are generally more complex to control and mechanically realise, and so are more costly. Each system was modelled using Lotus Vehicle Simulation (LVS) to understand the potential benefits in fuel economy and to assist in setting targets for the next stage.

The study included basic packaging investigations and a major goal was no modifications to the base vehicle's chassis, body or structure. A further important factor of the study was the ability to implement any solutions into production in a relatively short term. This drove the designers to use existing technologies and proven systems, wherever possible.

The conclusion of the concept study was to develop a parallel hybrid combined with a continuously variable transmission (CVT) in a twin clutch arrangement as seen in the diagram below. This would allow us to demonstrate both micro– and full hybrid capabilities combined with a continually Variable Transmission with no compromise to the driving experience of the vehicle and offering a near–term solution.



Schematic of the EVE Hybrid powertrain

The overall targets for the programme defined during the concept study, were:

- Improved fuel economy of 52mpg
- Emissions at Euro 4
- Acceleration 0–60mph in 9.0 seconds (0–100kph in 9.5 seconds)
- Vehicle maximum speed 180 kph
- Electric vehicle maximum speed 50 kph
- Electric vehicle range 5km at 30kph

System simulation and control strategy

Once targets and specification's were set, detailed computer–based models were developed and correlated to measured acceleration performance, maximum speed and drive–cycle fuel consumption data. The models were used to perform an initial sizing study for the hybrid vehicle motor and battery. The vehicle modelling work was performed using LVS, which enables the user to build a virtual vehicle drive line and test it over a drive–cycle (the new European drive–cycle, NEDC was used). Once the vehicle configuration had been determined, the vehicle model was used as the basis for developing a control strategy. This control strategy determines the instantaneous power split between the motor and engine and is computed based on the efficiency maps for the motor/generator and engine. The energy–management strategy control algorithm was developed in Simulink (LVS is able to link directly to MATLAB/Simulink and can be directly implemented into the vehicle controller using autocoding). It was optimised, using the vehicle model linked to Simulink, to reduce the fuel consumption of the vehicle. Another key objective of the energy–management strategy was to ensure that the battery state–of–charge was maintained within acceptable limits.

With this complex control strategy in place, the EVE Hybrid will consume over 25% less fuel than the standard vehicle over the NEDC. Additionally, the computed 0–100km/h acceleration time for the HEV is over 2.5 seconds lower than that for the standard Gen2 vehicle.

So what does retro–integration involve?

Certainly many changes have been made to fully demonstrate and evaluate this approach. Starting with the engine, various changes were made to the Proton gasoline 1597cc CamPro unit. The main modification was the redesign of the front–end accessory drive (FEAD) to accommodate a starter/alternator for the stop/start functionality. This unit switches the engine off when the vehicle stops, restarting the engine automatically when the brake pedal is released.

As a result, noise, emissions and fuel consumption are reduced. This change also required a new double–acting belt tensioner to cope with the new belt drive loading created by engine start condition. The heating, ventilation and air conditioning (HVAC) was also exchanged for a hybrid unit that operates as a conventional belt drive compressor and has an additional electrically–driven capability which enables continued air conditioning operation when the engine is stopped.

During the FEAD redesign, the opportunity was also taken to replace the belt driven PAS and water pumps with electric units to enable the investigation into the economy benefits of such units. To accommodate the additional engine hybrid functionality, the engine management system (EMS) was updated to a torque–based unit and re–calibrated.

Due to tight packaging constraints and to minimise any loss in overall vehicle performance, bespoke electric motor and power electronics were developed in conjunction with specialist suppliers. The 30kW, 144V electric motor is positioned between the engine and transmission. It delivers electric drive or regenerative braking via an additional clutch linking the motor to the drivetrain. In this way it can provide the same start–stop functionality as the starter/alternator with the additional benefit of electrical drive or drive assist, either boosting the drivetrain performance or providing economy and emissions benefits by operating as an electric vehicle.

A motor/generator of this size and its power electronics generate a great deal of heat and so are water–cooled with their own cooling system which required the design and packaging of an additional pump and radiator.

An additional single–plate clutch with concentric slave cylinder is packaged inside the motor and connects the engine to the electric motor. This enables the engine to be switched off for electric drive–only use. This clutch is controlled by an additional hydraulic control pack and is supplied with hydraulic power by the electro–hydraulic power steering pump. The clutch is controlled via servo valve and accumulator by the hybrid control unit

A CVT has replaced the conventional transmission, of which the bell housing was modified to accommodate the electric traction motor. The integration of a CVT gives benefits in fuel consumption and emissions control. In addition, its compact package assisted in the application of a hybrid electric drive and it provides smooth acceleration and low transmission noise.

The EVE Hybrid continually variable transmission

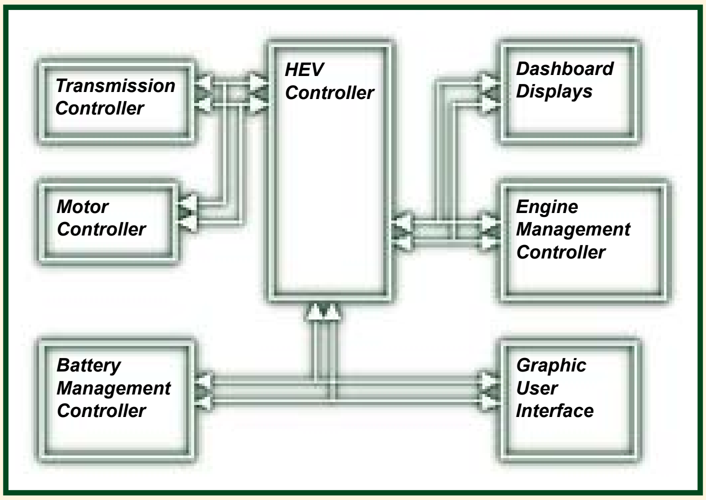
To store electrical energy, the EVE Hybrid uses a 30kW, 144V, Cobasys Series 1000, Nickel metal hydride (NiMH) battery pack with a capacity of 8.5Ah. It has been installed within the boot and incorporates a built in battery management system and an integrated liquid cooling system, which is cooled via air conditioned cabin air taken in through the speaker grill and expelled through a vent at the rear of the vehicle.

The base CamPro engine mated to the motor/generator and CVT

Making all these systems work together required a sophisticated bespoke Lotus Engineering control unit and software. These have been developed to monitor and control all sub–control systems including the engine management, motor/generator, transmission, HVAC, additional clutch, electro hydraulic PAS pump, starter/generator and battery pack.

This Hybrid Control Unit (HCU) is designed around the real–time, floating point Data Signal Processing (DSP) operating at 200MHz. The main processor supports Mathworks RTW Autocode which has been used to develop the control algorithms. All parameters and variables can be examined by a firewire interface connected to an external PC in addition to an ETAS INCA interface support via CAN.

Various vehicle systems were impacted by the introduction of the hybrid systems. To maintain the integrity of the braking circuit when the petrol engine is off, an electric vacuum pump was added to maintain the vacuum assist for the brakes. An electro–hydraulic power–assisted steering pump has been fitted, which allowed the retention of the existing steering column and hydraulic steering gear. This pump also provides hydraulic pressure for the additional



A sophisticated HEV controller interfaces with the powertrain systems

clutch that engages the hybrid motor. The front suspension was tuned to accommodate the redistribution of vehicle mass. The 12V battery was updated to a more robust gel–filled fibre mat unit due to the changes seen in usage and relocated to the boot to provide more space for the auxiliary power supply, which provides 12V from the high voltage system.

Changes to the conventional engine cooling system required analysis and development work to implement an electrical cooling pump and accommodate the impact of additional radiators, an oil cooler for the transmission and a secondary radiator for the traction motor and its power electronics.

It is a testament to the ingenuity of the installation of the hybrid system that there is little evidence of it in the interior. The only obvious changes are that the instrument panel incorporates an additional LCD touch screen display to show battery charge, power split between engine and motor, fuel economy and charge/

The hybrid system elegantly packaged without changes to the vehicle structure

The EVE Hybrid

discharge rate, and incorporates associated warning indicators where appropriate. Also fitted to the dash are new switches to select the car's operating mode – micro–hybrid, full hybrid or electric vehicle. The gear lever was also changed to match the requirements of the new transmission.

Another viable green vehicle the Lotus way

Following the complex assembly and installation process and a development phase to ensure faultless running of the complex control strategies, all the changes made result in the EVE Hybrid, a vehicle which has successfully demonstrated the retro–integration approach of these advance technologies. When compared to the original vehicle, there are both performance and efficiency benefits that validate the approach. Operating in its full hybrid mode, there is an impressive 22% reduction in CO_2 from 172g/km to 134g/km equivalent to a 28% in fuel economy. In micro–hybrid mode alone, there is a 5% improvement in CO_2 emissions and fuel economy. In themselves, these figures prove the success of the car and the project – significantly greener performance through an affordable implementation – but actually in full hybrid mode the EVE Hybrid has 0–60mph acceleration, performance improved from 12.6 seconds to a remarkable 9.0 seconds. It is yet another example of Lotus producing viable, green automotive solutions that are not at the expense of performance or driving pleasure.

Source: Steve Doyle

Group Lotus plc

Head office:
Lotus Cars Ltd
Hethel
Norwich
Norfolk
NR14 8EZ
United Kingdom

Editor: Peter Morgan
E: proactive@lotuscars.co.uk

just–auto.com

Head office:
C/o Aroq Ltd
Seneca House
Buntsford Park Road
Bromsgrove
B60 3DX
United Kingdom

Contact: Mike Gove
E: mike.gove@aroq.com