11 Collaboration – Innovation in Manufacturing

CASE STUDY 4: THE LOTUS ELISE

THE PHILOSOPHY BEHIND LOTUS AND THE ELISE

A proper sports car should weigh little, handle and ride superbly, and deliver high levels of driver satisfaction.

Colin Chapman, Lotus founder

The Lotus Seven, launched in 1957, had been Chapman's first car to be built on a commercial scale – previous models had been built exclusively for racing purposes. By taking his cars to market he wanted to transfer some of the excitement of racing cars to the road[1] The Lotus Seven offered racing car qualities at kit-car prices, with performance achieved through lightweight construction rather than a powerful engine. Chapman was quoted to have said, 'It is a bit like a four-wheeled motorbike.'

In 1966 Lotus, which had started off on a site in Tottenham, London, moved to its current site in Hethel, Norwich. The site, which had been the home of a USAAF Liberator squadron in the Second World War, was chosen not only because it would offer ample room for expansion, but also because it would allow the building of a great test track on what was the former runway and the airfield perimeter road. While keeping the driving fun, Lotus moved decidedly upmarket with the development of the £60k Esprit in the 1970s, a direction that was substantiated through the introduction of the Elan, a two-seater sports car, in the 1980s. Neither of the cars has ever been built in large quantities.

Group Lotus plc consists of two parts: Lotus Cars Ltd building the Lotus vehicles, which at time of Elise development had about 500 staff, and Lotus Engineering, acting as a consultancy to the automotive industry, which had about 800 employees. Both parts of the business, each generating about half of the company's revenue, are located on the same site. While they normally operate quite independently, they operated closely on the development of the Lotus Elise.

While the company had taken on engineering work for outside companies on a consultancy basis before, a separate Design and Engineering side of Lotus was set-up in 1986. In 1998 35 designers and modelers were employed by Lotus. Russel Carr, Chief of Design, explains, '50% of all the work that Lotus Design does is for third parties. The volume of work has increased several-fold over the last five years.' At Lotus' new design centre in Hethel with its two independent units, officially opened by the prime minister of Malaysia in October 2000, they can now run two vehicle programmes independently of each other.

In its drive to deliver lightweight, fast cars innovation has always played an important part. Says Kenneth Sears, Head of Vehicle Engineering, Lotus Engineering, 'One of the things that people identify with the company is gaining some performance advantage through the development of new technology.' Explaining what Lotus means by innovation...
a company representative explained, ‘Innovation must combine elements of knowledge, information and creativity. This means that engineers now and in the future need to combine individual and team working skills.’ It also means that the company is strongly committed to research and development, and the development of new products.

Previously owned by the Italian company Bugatti International, which had bought Lotus Group in 1994, the Malaysian car manufacturer Proton took a 64% stake in the company for £51 m in October 1996 with its chairman, Tan Sri Yahaya, buying an additional 16%. When Yahaya died in a helicopter crash, his share was bought by Proton in June 1997, bringing the company’s share in Lotus to a total of 80%. The remaining 20% are still held by Romano Artioli.[2]

**CONCEPTION AND CONCEPT**

*Don’t follow the crowd and copy what they are doing.*

Alastair Florance, Lotus Cars

There were several threads that together led to the conception of the idea for the Lotus Elise, or project M1-11 as it was originally called. The company was looking for a follow-up product to the Lotus Elan, which had proved far too expensive to produce and was rather complex to manufacture. The last straw had been that the Japanese company that had supplied the engines for the Elan had closed down. With the discontinuation of the Elan in June 1992, 200 jobs were lost.

The Elise started with a clean sheet, the only guideline was that it had to be true to the spirit of the founder. To fund the experimentation and development necessary for an entirely new car it was agreed that money would be diverted from the research budget of Lotus Engineering under the condition that the new car should be a demonstration of Lotus’ engineering and technology skills. In fact, it was the research budget of two years that was ‘liberated’ for the development of the Lotus Elise.

It was agreed that the money available should be invested in the development of those parts that would really make a difference, parts that would contribute to the car’s character and advancements in technology. In addition, a member of the development team was tasked with maximizing the number of components that were readily available and would not compromise the car’s design and character. For example, the cost involved in developing a door mirror in-house would have been in no proportion to the value created through its uniqueness, so a readily available model, from the Rover Metro, was used instead.

The design brief started from a corridor conversation of a few people – including Kenneth Sears, then Head of Technology Strategy, and Roger Becker, Head of Vehicle Engineering – about what a new Lotus car should look and feel like in November 1993. Soon after the design team began its discussion about the philosophy for the new car concept. Unusually, rather than starting with an engineering specification, this project started in the design centre. A few parameters were clear from the beginning; it had to be an open two-seater sports car that would be fun to drive, and it should not cost the world. Three years were anticipated from conception to production, as was a production run of a couple of thousand cars.
The designers started by putting together theme boards through which they explored customer characteristics and defined the mood and feeling that the car should have. Such boards would be covered with pictures of cars, aircraft, fashion items, celebrities, advertisements and motorcycles such as Ducatis, a passion for which was shared by Richard Rackham, Head of Engineering, and Head of Lotus Design, Julian Thomson. Richard went into raptures about it, ‘The bike has some awesome performance. You will never use all of it, but you know it is there. It is a bit of a toy that you just love owning. And if you take the clothes off a Ducati you see lots of nice things, that’s what we wanted to achieve with the Elise.’ Richard and Julian kept discussing the concept in all its aspects during work as well as when they met socially.

Once a philosophy had been agreed the designers would spend about six weeks developing sketches. Through the sketches key aspects were discussed and agreed: it was to be a step-in two-seater with the engine located at the back, set quite low. The question always asked was, is this in the spirit of Lotus, would driving such a car be fun? The team also used a buck made out of fibreboard, mounted on a wooden frame called the ‘seating buck’, through which the relationship of driver to driving controls, such as the steering wheel, pedals and gearstick, could be explored. In addition to mood boards, sketches and the cardboard model the team brought in a whole host of previous Lotus models.

With some key aspects and overall lines agreed, a first scale model was developed. This initial 1:3 scale clay model would demonstrate how the car was anticipated to look and what the basic elements would be. Rather than using the clay model for presentations, a plaster case would be taken from it from which fibreglass models would be made. This had the advantage that the original clay model could be used for further development, while the presentation model would be much more attractive and representative of a real car than a clay model could be. Once completed, the fibreglass model showed some flaws. For example, the proportions of the car did not seem right, it was too short and the overall height had to be reviewed.

Even though the Lotus Board had approved the development of a new car in-house in January 1994, the team faced its first big challenge only a month later. Unbeknown to the Lotus team, Artioli had invited other design consultancies to come forward with designs for a new Lotus car. Julian recalls, ‘Mr Benedini, Bugatti’s representative, got the Lotus Board down to decide which design they liked best.’ It was fortunate for the in-house team that their idea was considered to be the most progressive, innovative and different – and more aligned with the key brand values of the company than the other designs. While following a similar philosophy to the Lotus Seven, the design team had made a conscious effort to differentiate the new product from the existing ones.
During a body review meeting held in spring 1994, for which a refined second 1:3 scale model was used, questions were posed as to the feasibility of a step-in design. Finding a satisfying engineering solution, mainly to achieve the necessary stiffness, would require time and was likely to add weight to the car. On the other hand, developing doors and windows would be quite costly too, and particularly the designers were very keen to stick to their original idea. As a compromise it was decided to give the team four weeks to come up with a solution. But before the four weeks were up vehicle legislation engineer Ken Evans dropped a bombshell: legislation decreed a maximum step-in height of 750 mm off the ground, a running board, i.e. a step, would be required. Ken pointed out that the line would only have to come down by 30 mm but the designers felt it would compromise the lines of their design. A major rethink was required, resulting in additional costs of about £1/2 million.

While the second-generation design changed several times, it showed many aspects found in the final car such as the side air scoops, the top-exit radiator duct, the character of the headlights and the round indicators.

The surface of the 1:3 scale model was scanned to develop a set of drawings from which a full-scale model would be developed. Developing a full-size model is quite an involved process, and often scaling problems mean that proportions have to be revisited. Richard compared this to scale toy models where certain aspects of the car look right only because they have been overemphasized. In developing the first full-size model, wood and foam would be applied to a steel frame which would then be sent away to a specialist. At the specialist the foam would be milled to 40 mm below the surface and spiked with pegs sticking out 60 mm, making the model look like a giant hedgehog. Upon return to Lotus, the model makers there would apply clay to the height of the pegs before sending it once again to the specialist who would then copy-mill it into the final, but still only initial, clay buck. At the time Lotus employed ten model makers, bringing in additional modellers on a contract basis if and when required. A team of four to six would work on a full-size clay model at any point in time, each on a specified area. The role of the model makers was to help designers and engineers to refine the design. Based on the clay model that returned to the factory in May 1994, the design was signed off and both Romano Artioli and Gianpaulo Benedini of Bugatti were part of the decision making-body.

A lot of the actual design was done ‘on the object’, for example height and positioning of the headlights. Clay had the great advantage of being easy to manipulate and change, bits could be taken away and added back on. By doing so any curve or shape could be achieved. Refinement can take quite some time and might leave some people wondering whether anything has actually changed, but spending time and effort here could make the difference between the end result being ‘great’ or ‘exceptional’.

While the full-size clay model was developed, the latest 1:3 scale model was tested in the wind tunnel by aerodynamicist Richard Hill. For lightweight cars to achieve high speeds efficient aerodynamics are particularly
important. Hill found what he had anticipated when first seeing the low, stubby design: the car had quite a high drag factor. Another aspect contributing to the high drag factor was the radiator duct. By reducing the lift at the front, the radiator duct caused an imbalance at the back, meaning that the car would lift under aerodynamic load. Not something one would want to experience in a rear-drive car. To address the problem Richard Hill used clay, Styrofoam and tape to build up the surfaces until the optimum aerodynamic performance was achieved.

When presented with the result Julian was quite taken aback. Not only did he feel that the design had been spoilt, there was also the question of whether this meant that the design had to go back to the Board for renewed approval. Richard Hill explained that he had taken the changes to the ultimate limit and that a compromise would have to be found. Project Manager Tony Shute commented, ‘The car was as aerodynamic as a brick! However, the car had style and whatever happened, we did not want to lose that.’ Richard Rackham too was a strong supporter of Julian’s design and keen to help find solutions that would maintain the visual identity. Under the mediation of other team members a compromise was finally reached, and a spoiler added.

Julian commented on the design process, ‘The important thing is to remember that all those decisions governing the size and layout of the package that are given by the body engineering department are relevant to us. We talk about the styling but my group is very much involved with the concept of the car; you find that all companies offering truly innovative products have to have a level of understanding between both groups. You can’t just have engineers produce something and then decorate it with different styles, they have to complement each other.’ Richard agreed saying, ‘Chassis design is more than just a structure, it’s part of the style of the car as well, because it’s so visible in the design.’ The team worked to progress engineering and design issues in parallel, as well as considering interior and exterior as each would impact on the other. The efforts were supported by the geographical closeness between the design and the engineering department, and a presence of key concept engineering personnel in the design studio.

A lot of attention was paid to detail. Having a single windscreen wiper was part of the desired look. But not only would it look racy, it was also cheap, and most efficient aerodynamically. The choice of a single wiper had implications for the size of the windscreen and with it the proportion of the whole vehicle. There were many legal requirements and from the outset there had been some doubts internally as to whether a single wiper would work. Julian remembers, ‘Our engineers were more interested in developing wiper systems that would fit any car.’ Lotus had also approached a French company specializing in complex wiper systems. But the tight schedule for the project meant that Lotus was looking for a solution within four months – rather than the 12 the French company declared necessary – which meant that they decided not to get involved. Determined not to give up, Richard Rackham experimented until he found a solution that worked. He commented, ‘The fact that I was familiar with the Citroen AX system probably helped to see what would be possible. I just tilted the wiper motor spindle and it worked.’ For the manufacture they eventually found a UK-based company but the design was, in the end done, entirely in-house by Richard.
Probably the tallest challenge for the team was to achieve all other ambitions within a limited budget – if you have lots of money you can achieve almost anything! To make the car widely affordable the price tag had been set at the £20,000 mark. To meet all challenges the team decided to strip out anything that was not absolutely essential, and have as many parts as possible with more than one function, so for example the front structure of the car, which was crash structure, also provided support for the radiator, aerodynamic wing and attachment for a tow hook.

CHASSIS DEVELOPMENT

While Julian and his team were working on the overall design, Richard Rackham, who had been involved in the development of the M1-11 even at seating buck stage, started to think about the chassis design. The target weight for the new car had been set at 650 kg – to put this into perspective, a Renault Spider Sport weighs about 930 kg and the MGF brings about 1.1 tons to the scale.

Some Key Players in the Development Team set up in January 1994 and their Roles

- Tony Shute – Project Manager, product engineering background, philosophy behind the car, its gestation period, has done a lot of the development driving
- Julian Thomson – Head of Lotus Design, designing the shape, styling process
- Richard Rackham – Head of Engineering Design, responsible for the design of the chassis and suspension, engineering issues, issues during productionizing process
- Luke Bennett – Manufacturing Engineering Manager
- Morris Dowton – Manufacturing Manager, Lotus Production
- Ben Wright – Purchasing and Procurement Manager
- Dave Minter – Executive Engineer, responsible for honing the ride and handling
- John Miles – details of damping set-up
- Alastair McQueen – Chief Test Driver

To determine the dimensions of the chassis, Richard and his team, together with Julian, started with a full-size plastic sheet onto which the outline of the car was pasted. The tapes that were used for the lines could be moved and reapplied whereby different colours were used for different parts, i.e. chassis, engine, and passenger: ‘Using this,’ said Richard, ‘helps us understand the interaction between car and “agent orange”, so called because for the occupant we use orange lines.’ From the full-size drawing computer drawings are produced which then allow working with the chassis and the positioning of individual components.

Before the start on the M1-11 project Lotus had been working with a British car manufacturer on exploring the use of lightweight extrusions for car structures, a liaison that had been set-up by Hugh Kemp, Technical Director at Lotus at the time. When Lotus’ collaboration partner was taken over by a German manufacturer the relationship ended rather prematurely. However, Richard had got hooked on the idea and decided to explore possibilities
for the M1-11, and Tony commented, ‘It is nice to have a big brother when exploring new territory but we are quite used to doing such things on our own. Our Board saw the visionary product and felt that our people had not only the necessary expertise and knowledge but also a good dose of enthusiasm to see the project through.’ Richard contacted a company they had worked with previously, the Danish company Hydro Aluminium, whose core expertise was in the building industry, but which had recently set-up a new division, Hydro Automotive Components.

Welded aluminium had been used for car structures before, but not to the extent Richard planned to use it. Using extruded aluminium would mean that the frame would be not only lightweight but also durable and corrosion resistant. A constraint inherent in the choice was that extrusions tend to be straight. Any bend would not only cost time and money, it would also create a weak point in case of a collision. Finding a solution that would use only straight parts and be aesthetically pleasing turned out to be impossible, and in the end two bends had to be integrated into the back part of the chassis. Hydro’s experience and expertise came into its own and a special and complex piece of equipment was developed for the bending. However, the bending had to take place in a part of Hydro located in England; this meant that the chassis parts had to be shipped back and forth a few times. It was agreed that once Hydro’s new plant in Worcester would be completed, production would be moved to the UK.

While open cars are often compromised structurally, requiring extensive stiffening to make them sufficiently rigid, the Lotus Elise with its aluminium chassis needed no additional measures. Despite its structure weighing as little as 154 lb, it met all safety standards and proved to have great torsional rigidity.

However, welding aluminium tended to reduce its strength, which would have to be counterbalanced by thickening the material. And there were more downsides, (a) welding would only hold the parts together at the seam, (b) as welding changed the properties of the material there was also the concern that corrosion might occur here and (c) heat-induced distortions could occur. The team did a lot of investigating and much research took place into possible solutions. In the end, to avoid an increase in material, and inspired by the use of glue in the aircraft industry, Richard decided to explore bonding. He found a partner in crime in Peter Bullivant-Clark at Hydro Aluminium Automotive Tønder, Denmark, who had been involved in Hydro’s previous explorations of the use of aluminium extrusions for vehicle spaceframes. He spent two years with the Lotus engineers encouraging them to ‘think extrusion’ and ‘think bonding’.

Hydro had used chemicals for bonding aluminium before, but there were no industry standards which meant that there would be no ready made solutions. Several companies were visited and interviewed before they signed up
Ciba, based near Cambridge, UK, to help address the problem. Bonding had several advantages: rather than just holding different parts together at the seam, it would bind them together through a patch. Bonding would also not be given to distortion. However, a downside was that once a bonded joint started to peel it would have the tendency to separate suddenly – and the idea of the Lotus Elise disintegrating suddenly in the case of an accident was not particularly appealing. To overcome the problem, special aluminium screws were used right at the edge of the joints. In fact, the screws, which were made of soft aluminium, when driven into the parts were actually slightly melting so they acted more like rivets and were hence called ‘screw rivets’. These screw rivets did not have to be very strong as their main function was to prevent the onset of peeling. Testing took place to ensure that corrosion would not be likely to happen.

But not only was the chassis made of aluminium. Richard recalls, ‘Once I got hooked I started looking at every part thinking, could this be an extrusion? For example, I looked at the ugly Metro pedal box we had initially intended to use. Next to it I had sketched an idea pedal – and suddenly thought “extrusion”? The resulting pedal did not only look elegant, simple and functional, but also turned out to cost a fraction of their steel equivalents.’ Other parts that were made of extruded aluminium included the door hinges, suspension uprights and the steering column mounting bracket.

The Elise derived part of its structural stability from two high-sided members on either side of the car, which were connected in front and rear by torsion boxes. Attached to the chassis were front and rear clamshell body sections made from lightweight composite materials.

The body panels were made of very light composite materials. Lotus had been involved in glass-enforced composites since the 1950s. About 20 different types of matting were used in the production of the panels. There are two different ways of producing panels. One was to use a closed mould, the other to use a number of moulds that are joined together: The latter required layering of the glass fibre by hand which was time consuming but had the advantage that several sections could be joined together and would come out as one piece. For example, for the front panel eight sections are joined together, 11 for the back. Matting would be laid up in a mould that had been prepared with a gel that would form a smooth, paintable surface. Sufficient curing times for the panels were important, the panels had to remain in the oven for 5–6 hours at 60°C, then stand for 24 hours before being put into the oven for another hour at 80°C. If cured too fast the panels would develop a tendency to buckle and distort.

Once the body parts had cured they would be prepared for painting. The first step was cleaning up and smoothing the edges, which was done with a water jet cutter. Next the panels would get two coats of primer, after which imperfections would be sanded off and another coat of primer would be put on. After that panels would be checked once more for flaws before a colour and clear coat are applied. That done the panels would be placed into an oven to dry for 80 minutes at 80°C. Another quality check would take place before panels would be moved on for assembly. In total there were 16 build stages for the Lotus Elise, each lasting between seven and 36 minutes.
Another type of composite material was used for the brakes, aluminium and silicon. It was much lighter than the conventionally used cast iron, and, given that it conducts rather than absorbs heat, it had the additional benefit that such brakes would not overheat.

GETTING APPROVAL

Getting approval for a new model could be a lengthy and frustrating process. There were about 25 major tests a car had to pass for obtaining European-type approval. More often than not a new type would fail in several of them, which would mean that the programme could be put back by as much as six months. The Elise team had worked hard and systematically to anticipate and avoid any major reasons for a reject. They tested everything they possibly could under a range of circumstances and conditions. The testing facilities at Hethel, such as the track and rigs, were used extensively to ensure any problems would be detected before the car went for approval. One example was noise emission. Instead of measuring noise emission on the finished product, a silencer was incorporated right from the outset, meaning that it was an integral part of the product as well as the production process – rather than having to be put in as an afterthought.

Several internal measures supported quality control efforts. People from engineering and process control met at the end of every day to discuss any issues that had come up during the day. Everyone could find out performance criteria such as production cost, delivery against targets, materials issue and so on from noticeboards that had been distributed around the shop floor. To ensure everyone could see how their work fitted into the whole, an instruction booklet was available, providing information on the parts used, sequence of assembly, move-up times, duration of each build stage, and so on.

Some of the initiatives had been prompted by the preparations for QS 9000 certification which Lotus obtained in 1997. QS 9000, the car industry’s equivalent of ISO 9000, had been a requirement from some of their major clients such as Ford and General Motors.

The team decided to go for approval in the Netherlands – not that the tests there were much different from those in the UK, but the team there had been particularly cooperative and helpful. There was only one aspect that had to be redressed for the Elise, the angle of the front windsreen which was considered to be too shallow. This had escaped the attention of the team as it became only obvious in the prototype – today, where everything would have been done on CAD, it could have been identified earlier.

But even that did not prevent the Elise from becoming the first car in the world to obtain the full European vehicle-type approval the first time around.

THE MARKET AND RESULTS

Strong design requires strong leadership.

Richard Rackham

When the car was first shown at the international motor show in Frankfurt in 1995 it caused a bit of a stir. Not only because of its exciting design but also because of the extensive use of aluminium in a way thought impossible.
before. Richard recalls standing next to the car and being approached by someone who turned out to be the project manager for the Renault Spider. The French project manager was completely taken aback by the fact that Lotus had managed to come up with a bonded aluminium chassis — just as he had aimed to do, but he had been told by his engineers that it was entirely impossible. Upon which Richard commented, ‘The car would probably not have been as daring both in terms of its design and components had decisions been made by consensus.’

While it had originally been planned to produce around 700 cars per year, since start of production in August 1996 it had become obvious that demand would by far exceed this mark. In May 1997, with a daily production of eight cars expected to go up to 12 by the end of that year, Lotus had an order book of 2000, which translated into a waiting list of 18 months. In handling that kind of demand Lotus’ dedicated, well-trained dealership was seen to be essential. Increased demand also meant that Lotus had to invest significantly in increasing production capacity, but even in January 2002 they had waiting times of approximately three months. And all that despite, as Tipler writes, ‘While other cars seem to have a clearer customer profile, it is not quite clear what attracts someone to Elise ownership.’ But Lotus were not too worried about customer profiles at that point in time, to quote Julian, ‘We don’t want to get overly involved in marketing, market research and clinics, that sort of stuff; that’s a lot of hassle. But I think what is important is how you pitch our car in terms of its image, how you separate it, how you use a brand. The luxury for us is that we don’t have to find hundreds of thousands of customers, we only need to find a few thousand. And the product we do can be even stronger for those people. That’s what we’ve done with the Elise: we’ve found a product that isn’t for everyone but definitely is for some people. And those people would never be seen dead in an average sports car. That’s our luxury. We’ve got a fantastic name. We’ve only got to find a maximum of 5000 customers a year, and we know there are nuts who’ll put up with all sorts of things. And we can build our brand and make it stronger. We can do a total enthusiasts’ car, we don’t need to do electric windows or NHV, or worry about a walnut facia. We can get away with blue murder compared with the others, and we can make a fantastic car that enthusiasts are going to love.’

**THE FUTURE**

In the *Autocar* magazine of 12th February 1997 Proton, the company’s Malaysian owner, outlined the following agenda for the company:

- Treble Elise production at Hethel.
- Establish Elise assembly in Malaysia.
- Replace Esprit with V8 supercar by 2000.
- Establish post-grad college for automotive engineers at Hethel by autumn 1997.
- Consider Lotus re-entry to F1 for Malaysian GP of 1999.
- Double earnings from engineering.
QUESTIONS

1. What can be learned from the use of prototypes at Lotus?
2. Discuss the role of collaboration with external companies.
3. Given the demand for the new product, what steps should the company consider?

NOTES ON CHAPTER 11

[1] Interesting to note that 25% of all Lotus Seven built have, at some point or other, been driven in races.

[2] In the late 1990s Artioli sold Bugatti to the German car manufacturer BMW.