The Design and Development of Microcab

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Abstract

The combination of the global economic crisis and the issues associated with reducing our carbon consumption has made the Microcab project both timely and relevant. The company is essentially a spin-out from Coventry University's design expertise. The project has been to design, develop and test a sequence of vehicles for urban transport using low carbon hydrogen fuel cell technology. The key process issue is whether a relatively straight forward and familiar design process can be followed up successfully by a design product evolution and testing programme which is complex. Its complexity is in its dependence on various funding sources, in its engagement with a changing array of development partners, and in its relationship to a number of public sector programmes.

Keywords

Industrial design, Eco-design, Sustainable design

The Microcab project is led by John Jostins who is located in the Centre of Excellence for Product and Automotive (CEPAD) at Coventry University. Established as the result of a successful bid to HEFCE's Centres of Excellence for Teaching and Learning initiative in 2005, CEPAD now has an expanded remit. It encompasses both pedagogic development and applied research, seeing these activities as mutually reinforcing. The author, as Director of CEPAD, has taken a direct role in managing and ensuring an appropriate context for the Microcab project.

The Microcab Project

The intention in the Microcab project has evolved during its development. When it was initiated in 1996 the vehicle concept was considerably further from the mainstream than it is now (in 2010). It can be summarised for the current phase of work as:

- To design and develop a vehicle for urban transport using low carbon, hydrogen fuel cell technology.
- To manufacture and test a number of vehicles

The design concept is a vehicle with good environmental characteristics. It incorporates a powertrain architecture which is modular and full optimisation of systems and components has not been attempted. Technology and component choices have been dominated by considerations of availability, practicality, robustness, affordability, and avoidance of the risks associated with emerging exotic technologies. The original inspiration for this extended piece of work came about as a response to urban congestion problems, particularly in large cities. The intention has been to design and prototype vehicles employing lightweight structures powered by means other than the internal combustion engine. A range of electric drive systems has been adopted for propulsion, initially using battery and solar power, but subsequently adopting hydrogen fuel cells.

Whole vehicle design has always been at the heart of the project, with specific purposes and users in mind (eg. taxis). This has allowed all aspects of the vehicle to be re-evaluated including developing a more sustainable drivetrain. There are two aspects to the current approach:

1) Low carbon footprint designs for vehicles can be different from those currently in use. Patterns of usage will probably change and this is an ideal time to offer up alternatives.

2) New drive systems offer new ways of packaging components in and around vehicles and therefore offer potential for better use of the space.

The project has grown steadily in scale allowing a range of experiments with alternative vehicles, fuels and drive systems. As global environmental concerns are being taken extremely seriously by governments and industry leaders, the future of individualised transport products is likely to be in the integration of engineering and design innovation. From that, new products could emerge for mass use.

Approach Used

As the Microcab project has developed, numerous partnerships with academic institutions, companies and other organisations have been formed to create a network of support structures to test particular concepts. Throughout its development the project has been led by John Jostins, who divides his time between running the Microcab company and as a professor at Coventry University. He has a background in motorsport and special effects for film and television. His original motivation to develop what became microcab was a very personal response to the frustration of experiencing the difficulties of urban travel.

John Jostin's role throughout, has been as:

- Project Owner
- Concept Designer
- Project Manager

For the intial design work John was joined by Mark Dickins (a Transport Design graduate) who did the concept design styling drawings. He produced design sketches under John's direction, acted as a sounding board, visualiser and then model-maker. This core staffing of two produced a 1/4 scale chassis model, followed by a full size automotive clay model, from which a grp shell was taken.

The earliest physical model (1/4 scale) on show at the Oxo Tower, South Bank, London. It was intended to be a pedal/electric hybrid.

The original concept was of a pedicab type trike. This was a pedal-electric hybrid which weighed 150 kilograms. Jostins was able to secure private investment of £20k which was sufficient to pay for the construction of a prototype. By August 1999 a full sized working vehicle which was half pedal-powered and half electric had been produced. To do this Jostins used industry contacts and called in favours from the cycling industry and others. Honda for example provided the electric motors. The prototype design was exhibited at Interlaken in Switzerland.

Interlaken, Switzerland for the European Velomobile Symposium - the first full size working prototype. Battery electric with pedal assist.

Experiments were carried out with three different drive trains and eventually single motor system was chosen. The tiny battery pack weighing 28kg was not very effective and hydrogen fuel cells were examined as an alternative as they are lighter and better for re-fuelling.

In order to be able to apply for public sector funding to develop the vehicle a project team was created. Zytech had worked in Coventry with LTI and added necessary fuel cell expertise. John Piper was a former colleague of John Jostins from the Williams F1 team, who brought chassis design expertise. The team was thus expanded to:

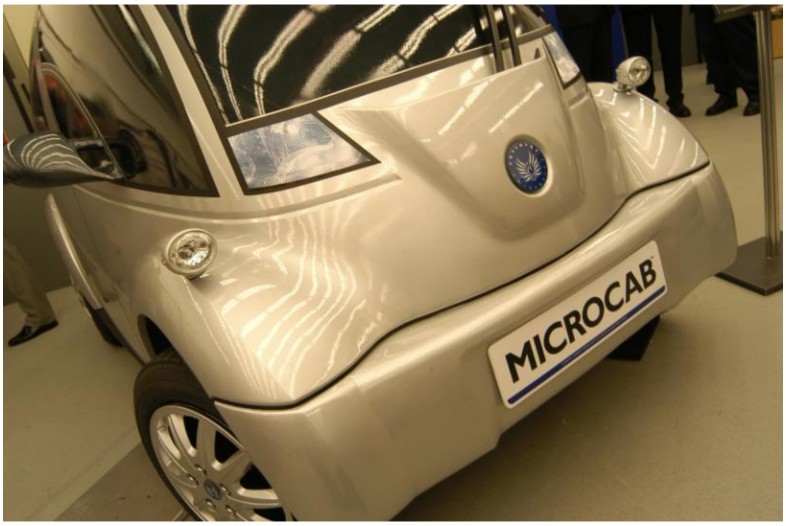
- Microcab
- Zytech Power
- Piper Design

This enabled an approach to be made to the UK Government for funding. The basis was a claim that at a weight of 180kg for the revised design the vehicle had an extremely light chassis which provided the appropriate framework for developing hydrogen fuel cell hybrid propulsion. The application to the DTI (Department of Trade and Industry) in 2002 for a SMART innovation award was successful.

The first prototype was reworked with a new, lighter, moulded carbon sub-frame, and a single motor geared up and driven through a differential shaft.

Development was still a little precarious and uncertain as Zytech went bankrupt and had to be replaced by Intelligent Energy to sustain the fuel cell expertise within the team. In order to provide greater stability Coventry University became an equity partner in the company, and provided development and funding support.

2003, working in the new Bugatti building facilities at Coventry University, a styling exercise, led by Geoff Matthews, looked at a possible new four wheeled Microcab design.



This stage in the development of Mircocab was based on 4 core partners:

Microcab Industries Ltd.,

Coventry University,

Piper Design,

Intelligent Energy

In 2004 this partnership provided the basis for an application to the DTI for a Research and Development grant. £145,000 was awarded to develop the principles of the previous prototype. Now numbered H4 the project commenced in April, 2004 lasting for 15 months, completed in July 2005. As with the preceding design, the H4 was an urban, ultralight, city speed, 'short hop' taxi or freight vehicle. One important consideration in the design was that vehicle should be able to carry a wheelchair-bound occupant.

Context for the development

Since the initial idea for Microcab the context for its development has been one in which it has moved closer to mainstream concerns. This has included the developing body of published advice and opinion which was considering alternative energy sources for vehicles, and various configurations and drive trains. Samples of such developments give an indication of the direction they have taken.

In 2002 Jeong et al proposed that the most promising vehicle engine that could overcome the problem of present internal combustion is the hydrogen fuel cell. Fuel Cells are devices that change chemical energy into electrical energy without combustion. Pure fuel cell vehicles and fuel cell hybrid vehicles (Fuel cell + battery) studies indicate that hybrids which can capture regenerative braking energy look most promising. Hybrid vehicles are superior to their non-hybrid counterparts (Jeong, K.S., and Oh, B.S. 2002). Hybridizing a fuel cell system with an energy storage system offers an opportunity to improve the fuel economy of the vehicle through regenerative braking and possibly to increase the specific power, and decrease the cost of combined energy conversion and storage systems (Ahluwalia, R. K. and Wang, X., 2005).

Fuel Cell vehicles will be quieter and will have lower non-GHG tailpipe emissions, but will be more expensive and will require new infrastructure for vehicle manufacturing and maintenance, and for producing and distributing hydrogen fuel- thus making rapid acceptance and market penetration more difficult (Weiss, M.A., et al 2003). Automotive manufacturers and suppliers are investing heavily in the development of fuel cell systems as potential power sources for light duty vehicles. At this point fuel cell vehicles promise to be far more efficient, clean and truly zero emission with the only by-product being water (Lee, H. S., et al 2003). Reports on trials with Scania Hybrid PEM Fuel Cell Concept Bus, using hydrogen stored in cylinders on the roof concluded that such vehicles have big potential, but that there are issue to be considered, relating to durability, lifetime, costs, vehicle and system optimisation and subsystem design (Folkesson, A., et al 2003).

Battery and hybrid vehicles are seen as today's sustainable mobility solutions, preparing a future shared with a hydrogen economy. The summary report of the EU High Level Group for Hydrogen and Fuel Cells, presented in June 2003, developed a vision of the contribution that hydrogen and fuel cells could make to the realization of sustainable energy systems in the future. However as a long term vision (2000-2050), there is a need to take a strong action in the short and medium term to address current environmental and energy concerns (Mierlo, J. V., Maggetto, G 2005). Because of their high efficiency and low emission potential, fuel cell vehicles are undergoing extensive research and development. However several major barriers need to be overcome to enable a hydrogen economy. Because fuel cell vehicles remain expensive, very few fuelling stations are being built. To try to accelerate the development of a hydrogen economy, the auto manufacturers are developing a hydrogen fuelled internal combustion engine as an intermediate step (Kwon, J., et al 2006).

The hydrogen era is foreseen following the European research programme in a time horizon of 2020-2040. There will clearly be a choice between the electron economy using directly produced electricity, and the so-called hydrogen economy, which leads to the introduction of intermediate hydrogen production, transport and distribution. For passenger transport/ delivery vans there is a big time gap between the looming oil shortage and 2020-2040 for the hydrogen economy. Hybrids and electrics are needed to fill the gap and the better they perform the more questions there are over hydrogen fuel cell vehicles (Mierlo, J. V., et al 2006).

Fuel cells are projected to have energy efficiency twice that of internal combustion engines. They can start in freezing conditions without significant deterioration. Hydrogen storage systems for vehicles are inadequate to meet customer driving range expectations without being intrusive. The transition to hydrogen-powered fuel cell vehicle is projected to occur over the next 10-15 years. In the interim fossil fuel consumption will be reduced by increased use of battery gasoline hybrids (Chalk, S. G., and Miller, J. F., 2006).

Various fuel cell vehicles have been designed and prototyped by a number of companies - according to one source some 40 vehicles by 16 companies (TUV SUD). These vehicles have not become available for evaluative scrutiny and are not available at an affordable cost for public sector testing.

In this context the argument for the design, development and testing of vehicles employing fuel cell technology, and available for public sector scrutiny in universities and government agencies, becomes fairly compelling. There was a need to respond to this requirement, which the Microcab group endeavoured to meet.

Design Development of Microcab

For the current version of Microcab the overall vehicle design was developed under John Jostin's leadership. For the vehicle re-design Jostins engaged Automotive

Design graduates Adam Fairless and Alan Barrett as concept design/stylists. They were responsible for:

- Design: styling sketches
- CAD
- Ergonomics rig
- Full size styling buck

The full size styling model was sculpted and milled in Coventry University's Bugatti automotive design studio. It was used to facilitate design approval sign-off.

This new vehicle design was exhibited at the Grove Fuel Cell Symposium in London in October 2005 (Jostins J., 2007)

The next stage in the development of Microcab was concerned with addressing the engineering and operational requirements of the design. The need was to move from a concept design with a good external appearance and sound spatial ergonomics which was functioning as a rolling prototype, to a vehicle design with proven technical capability. This required considerable development. The UK National Engineering Laboratory in East Kilbride needed a test vehicle to sustain their programme in 2006, and Microcab was able to fill the gap. Their test results confirmed the viability of the design, and clarified the direction for future technical development.

However depending on the serendipity which had made available the East Kilbride facility was not a very secure strategy. There was a need for a greater focus on making the company viable, and on collaborative arrangements to sustain intellectual and financial investment. At this point Mike Wade joined as an equity partner bringing expertise in small manufacturing company start-ups, and investments.

The necessity for this was made apparent with the loss of Piper Design from the group due to bankruptcy. As a number of Piper’s engineers then moved to Delta Motorsport Ltd, it was appropriate for Delta to replace Piper in the core consortium. This meant that individual contacts could be maintained.

The key to the next stage in Microcab’s development was Wade’s bringing a second University into the programme. His approach was to the Chemical Engineering Department of the University of Birmingham. In a programme of research led by Professor Kevin Kendall the department was already investigating CHP (combined heat and power) and canal boat propulsion using hydrogen fuel cells. They were quite amenable to extending their activities to encompass Microcab. However for this to be feasible a further funding source was necessary.

Design: technical details

What was needed for Microcab was that its technical details be developed and tested through running protypes. Its technical package consisted of its powertrain and the vehicle structure.

The powertrain is a fuel cell series hybrid, with a relatively small battery pack to deal with power transients and provide for short periods of operation on stored energy. (Tovey, M. 2009). This enables adequate performance with minimal fuel cell power output, giving benefits in cost and simplicity. If fuelled with hydrogen generated from renewable sources, this gives a truly zero-emissions fuel cycle. Current vehicles, designed for limited low-speed operations only, use the following components:

- Dynetek carbon-composite cylinder storing 0.63 kg hydrogen at 350 Bar
- Ballard Nexa fuel cell system, producing ca 1.5 kW at 24 V, with DC/DC converter
- Sealed lead-acid batteries 48V, approximately 35 Ah

- GE motor (wound, 48V DC, brushed, separately excited) rated at 4 kW continuous, 11 kW peak
- GE electronic drive, including simple regenerative braking (rear wheels only)

The vehicle structure has been designed with a frame holding lightweight GRP panels and vacuum formed plastic parts. The intention is to minimize weight with a target of 450kg. The current test vehicles have steel chassis components partly in order to allow modifications as required, and as a consequence are heavier. It has been necessary to use standard parts from production vehicles for reasons of availability and cost. The chassis has a sandwich structure with the steel frame assembled around it to contain the fuel cell, motor and hydrogen tank.

The original intention to use regenerative braking has not been retained in the current prototypes. The intention was to recover power from deceleration but this proved to be unsatisfactory in practice. This was because short pulses of high current generated on deceleration could not be absorbed by the batteries.

As anticipated, issues related to hydrogen safety required considerable attention to design details. There is a requirement for leak testing and monitoring, for avoidance of any accumulation of gas, and for other measures to comply with the draft European safety standard for hydrogen vehicles.

Fuel economy and range of existing vehicles are compromised by low efficiency of the mature, off-the-shelf fuel cell, the extra power converters, and the motor. However general performance has been fully satisfactory for trial purposes.

The limited budget, requiring maximum use of standard components and the prohibitive costs of carbon fibre, engineering and tooling have required major compromise on weight, with vehicles weighing approximately 650 kg against the original design target of 450 kg. The effort required for electrical integration of the fuel cell and other vehicle systems was underestimated and a wide range of electrical system revisions has taken place. Overall packaging was relatively straightforward, because the vehicle design is spacious, the all-electric powertrain facilitates a modular approach, and the low energy requirement results in small sizes of fuel cell and batteries (Tovey, M., 2009).

Birmingham University Project

The Birmingham Science City Project is part of the UK Government's Hydrogen, Fuel Cells and Carbon Abatement Technologies (HFCCAT) Demonstration Scheme. The scheme is designed to address key energy priorities of cost competitive carbon emission reductions and increased security of supply. A number of projects are being funded throughout the country. The Birmingham scheme is also supported by the regional development agency, Advantage West Midlands (AWM).

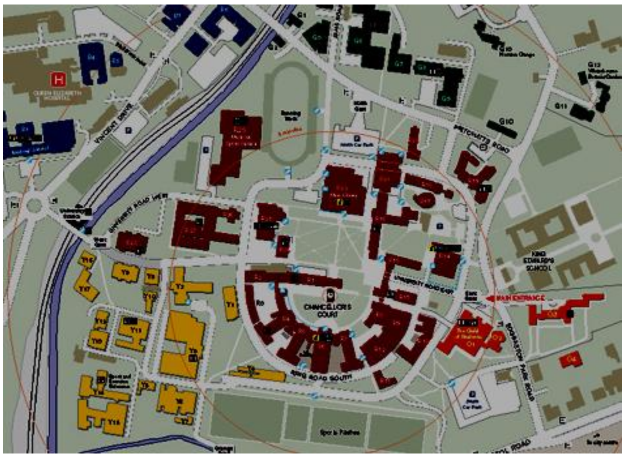
HFCAT project proposal created with funding support from three sources;

Science City (pays for vehicles)

AWM: hydrogen fuel station.

DTI: project funding.

The Birmingham project includes commissioning Microcab to supply and operate 5 of its vehicles on the Birmingham University Campus. It provides a good test arena for evaluating the vehicles on real roads where there is mixed use, but off the public highway. Part of the facility is a dedicated hydrogen fuel station




the fleet of five vehicles at the University of Birmingham

The project began in November 2007. The plan has been to investigate the use of the vehicles through various cycles of operation. A number of tasks have been trialled including postal and food deliveries, taxi services for visitors and estate duties. The intention has been to produce results which would allow comparison with the types of standard diesel vehicles currently used for such operations.

The filling station which has been installed contains hydrogen at 400bar. The filling operation was planned to take 4 minutes to pump 0.6kg of hydrogen into the carbon fibre/aluminum core composite storage tank at 350bar. The hydrogen is fed to the 1.2kWe Ballard Nexa PEMFC system which provides current direct to the motor and/or recharges the batteries to give a predicted 100 mile range. On campus that should be sufficient for 5 days of operation, making refuelling a weekly task.

The project which is now 50% completed involves 23 separate work packages, delivered by 8 separate organisations:

1. Microcab Industries Ltd
2. RDM Ltd
3. Delta Motorsport Ltd

(1–3: microcab consortium.)

4. The University of Birmingham – demonstration site.

5. Coventry University
6. Westfield Sportscars Ltd
7. Potenza Technology Ltd
8. Tempus Developments Ltd

The early work was reported on by Kendall, Pollet and Jostins (Kendall, K., et al 2008). They identified the basis in the development of hybrid fuel cells in previous work (Kim, M. J., and Peng, H., 2007), (Schell, A., et al 2005), (Lin, C., et al 2006), (Vahidi, A., et al, 2006).

In a recent technical paper Kendall et al described the Microcab test fleet test as the largest such trial in England to date. Their conclusion was that the hydrogen filling of the vehicles with green hydrogen could operate successfully on the university campus. Vehicle performance was good in terms of acceleration, cruise speed and range, satisfying the campus drive cycles. However the regenerative braking system was not adequate and needed improvement. Further optimization in terms of efficiency and reliability was required and a more powerful hybrid drive train would be needed for the ECE15 urban drive cycle (Kendall, K., et al 2010) and (Kendall, K., 2009).

Further Projects

There is regional support for further development work on the vehicle design through the regional development agency Advantage West Midlands. It is funding a research and development programme for small companies who are involved in the development and manufacture of vehicles and members of its Niche Vehicles Partnership. Microcab is a member. It is managed and led by CENEX, the Centre of Excellence for LowCarbon and Fuel Cell Technology, and supported by Coventry University, which both hosts the project and delivers the programme.

The Niche Vehicle Network consists of some 37 organizations. Microcab's development programme involves 3 of them in collaboration, along similar lines to the Birmingham project.

Microcab

RDM Automotive

Delta Motorsport

Further, through the Technology Strategy Board, the UK Government has announced that it is supporting CABLED (Coventry and Birmingham Low Emissions Demonstrators), as part of its Low Carbon Vehicle Demonstrator Programme. This will be delivered as 8 projects nationwide featuring 340 vehicles showcasing a range of technologies. About a third of these will demonstrated in CABLED and Microcab has been asked to provide 10 fuel cell vehicles for the trial, the only hydrogen vehicles in the scheme. This builds directly on the Hydrogen Fuel Cell and Carbon Abatement Technologies (HFCCAT) project at UB and extends the reach of it to Coventry.

Conclusions

The initial design process for Microcab has been successful. The complex design development programme has clearly had some success. However it is incomplete and there is a difference between the successful completion of its various programmes, and the overall achievement of a successful and proven product.

A key characteristic of the project has been its dependence on public sector funding. Its being timely and contributing to longer term future rather than short term economic returns has been an important component in arguing for such support.

The organizational components which have been crucial to its survival are probably twofold:

- The role of John Jostins as the project manager has been essential.
- Maintaining a small core of collaborating companies to design and make the vehicles has ensured a manageable approach.

The medium term future for Microcab will depend these elements being maintained.

Michael Tovey

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Author Biography

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A graduate of the RCA, Professor Mike Tovey was in industrial design practice prior to entering education. In 1973 he joined the institution which was to become Coventry University, as a lecturer in industrial design. He was appointed to Head of Industrial Design in 1985 and in 1989 was made Dean of the Coventry School of Art and Design. In 2007, he changed position to take on the University-wide post of Director for Design. Professor Tovey is responsible for developing courses and applied research in design across the University and is Director of the Centre of Excellence in Product and Automotive Design (CEPAD).