

2430

3560

Adverse Camber

Stage 7

60% Rough
Tarmac

35% Smooth
Tarmac

5% Gravel

Double Crest



McRae R4-e

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M6X01244-CW2

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Summary

The ultimate goal of this project was to create a feasible, fully electric, rally car for the 2030 season. As internal combustion bans loom, all mainstream manufacturers will be forced to move to alternative fuels to power their vehicles. Eventually, this will filter through to much of the motorsport world too. In order to further the development of electric vehicle technology, its adoption into motorsport could prove vital. History has shown repeatedly that a wealth of innovations that we take for granted on our road cars were originally dreamt up and created in motorsports (Rowswell, 2019). This project aims to continue this trend, with a focus on the development of clean energy.

Outcome Specification

Parameter:	Description:
Target Customer	WRC teams – both with and without full factory support.
Aesthetics	The aesthetics are minimalistic, partially package driven and feature aggressive aerodynamic elements.
Ergonomics	The car is able to safely house the driver, co-driver, mandatory spare wheel and the roll cage.
Size	The vehicle conforms to the Euro B Segment standard, coming in at 3.6 m long, with the maximum being 4 m.
Performance	Capable of producing a total of 840 HP (210 HP per motor), the vehicle is high performance and motorsport competitive. With the four individual motors controlled through a computer module, power distribution can be locked or fully dynamic. With a short single gear, it is focused on acceleration for better performance on rally stages.
Environment	Thanks to the technological advantages afforded by graphene supercapacitor technology; the vehicle will be able to operate more consistently and reliably in extreme climates, compared to a traditional lithium ion setup. This is further bolstered by a dedicated cooling system.

Production Quantity	As a result of the production methods and materials used, the vehicle can be produced on demand. Consequentially, the minimum quantity of 250 variants, specified in the proposed rule set, could be easily satisfied whilst using a small production facility. Parts could also be made on demand as required by teams for servicing and accident repair.
Manufacturing Properties	The small carbon tub chassis is easily produced on demand thanks to its simplicity and small size (Berman, 2015). Body panels can be bonded to the chassis in order to complete the overall construction of the car, thus allowing only damaged pieces to be replaced in the event of a crash. Using moulds results in low tooling costs and ease of production on demand.
Materials Properties	The materials that make up the vehicle are not merely sustainable, but also incredibly safe and strong. The carbon fibre construction of the vehicle allows it to effectively absorb impact without significant deformation of the passenger cell (Berman, 2015), especially when coupled with the mandatory roll cage. However, the materials and process are expensive and labour intensive, resulting in a homologation model that will be more expensive – comparable to high-end sports car price tags. However, given its light weight and high power output, it will still make for a thrilling driving experience for the wealthy enthusiast.
Target Product Cost	Currently, WRC cars have a price tag of around £500,000 (Evans, 2011). A large proportion of this price comes in converting a standard road car and transforming it into a motorsport version. By designing a rally car from the ground up, much of the extra engineering required is not necessary. However, thanks to the exotic materials and cutting edge battery technology, the cost of the vehicle would still be around £750,000. The homologation model would make use of less extreme motors and batteries, as well as not requiring many of the FIA safety systems for road use. This would result in a vehicle costing closer to £150,000.
Launch Date	The technology and design make the target of a 2030 launch perfectly feasible.
Sustainability	Sustainability is a great strength of the vehicle: not only does it benefit from a renewable power source, but also the application of recycled materials. Its combined use of materials that are both recycled and recyclable would result in an environmental footprint that is drastically reduced in comparison with a vehicle made from all new materials. Additionally, the batteries can be charged using renewable energy (solar, etc) and have a significantly eco-friendlier life cycle than lithium ion cells.

Evaluation

Despite much of the design remaining faithful to the proposed 2D drawing, several changes were made to improve aesthetics and ensure useability. The first of these changes was to the surfacing on the side of the vehicle. Originally designed with an additional shoulder line parallel to the vent, it was to flow into the body near the front wheel arch. However, early 3D drafts highlighted the difficulty in turning this into an attractive design element. I decided that it appeared too awkward from many angles and it negatively impacted the overall design.



Therefore, the decision was made to reduce its impact and integrate it into a more traditional shoulder design element. This ensures that the design retains its individuality whilst making it more palatable. A styling line was added on the CAD model in its original position as a call back to the proposed design and to complement the lines of the side intake (Fig 1).

The second modification made was to reduce the curvature of the rear wing. Much like the previous change, the wing was adopted following a review of the 3D perspectives, first in CAD and then with the physical model. The updated version of the wing was designed to be reminiscent of that of the Ford Sierra Cosworth (Fig 2), with a much squarer appearance (Fig 3). However, it later transpired that the more 'squared-off' version first used in the final design was not quite dynamic enough. As a result, I created a slightly more rounded version, which better suits the other elements on the car, whilst integrating more effectively with the retro inspired elements. This proved to be the best balance of modern lines alongside retro appeal that I was looking for (Fig 4).



Fig 3



Fig 4

Finally, modifications to the overall dimensions of the car were made in order to improve its proportions in 3D. Similarly, to enhance the stance and lines of the car, the width was increased from a proposed 1760mm to 1880mm. The height of the car was also drastically reduced, from a proposed 1870mm to 1050mm. It should be noted, however, this is partially a result of a typing error in the original drawing. The length and wheelbase were also shortened slightly in order to bring the vehicle closer to the current generation of rally cars. This will help to improve the manoeuvrability of the car and increase its performance. Additionally, this change impacted positively on the proportions of the vehicle as a whole. In short, the limited redesign more effectively showcases the vehicle's relation to its rally heritage.

The physical aluminium model produced from my CAD data proved invaluable in allowing for significantly deeper analysis of my final design. As previously mentioned, viewing it up close and from an in person perspective allowed me to rethink the design of the rear wing, helping to improve the final outcome. By producing and assembling the model, it helped me to appreciate the importance of thinking in three dimensions when designing, in order to ensure the best possible outcome for the project. One inconsistency with the CAD and prototype model is that

the wheels are wider than they would be on the actual car, in order to ensure that they are able to cope with the weight of the solid aluminium body.

Similarly, the creation of the CAD model allowed me to more effectively visualise both my design and any changes that I was considering during the design process. Whilst I initially struggled with the Autodesk Alias software, I was able to reacquaint myself with its functions to produce my final model to a high standard. In order to ensure consistency with my final design and dimensional accuracy, I used the orthographic design proposal as an underlay to create the surfaces of my model. As well as Autodesk Alias, I made use of Solidworks to create the wheels for the vehicle. This is due to my familiarity with Solidworks and my ability to produce more less complex parts much more effectively. Whilst unconventional in design, the wheels selected in my final design partner both the lines of the car and its futuristic, eco-centric ethos.

Outcome Comparison

The aesthetics of the designed outcome are very close to the initial proposal and brief set by the original product design specification. The overall design is minimalistic, caters primarily to the technical packaging and is highly functional. The aerodynamic elements are large and aggressive, whilst still flowing with the overall shape of the vehicle, in a manner similar to the rally icons of the 1980's and 1990's. In short, the design of the vehicle shows lineage to its rally predecessors. Such elements include round spotlights, aggressive aerodynamic pieces and a wide track.

The final outcome has been accomplished with user ergonomics in mind throughout the entire design process. Several alterations were implemented over the course of design development in order to ensure that the vehicle would be fit for purpose and meet the initial design specification. These included expanding the greenhouse, increasing overall width and shortening the wheelbase. As a result, the final outcome is capable of housing two large adult males wearing XL size racing helmets, whilst also providing sufficient clearance for the internal roll cage. Additionally, all powertrain components are housed within the wheelbase and below the belt line of the vehicle, thus ensuring optimal packaging and performance capabilities (Within, 2015).

Furthermore, with the super capacitors ability to be removed from beneath the vehicle, it is not simply the driver and co-driver's ergonomics that were considered. The built in lifter system permits the battery systems to be quickly dropped out from underneath the car and replaced when charging is not an option or emergency maintenance is required. The implementation of the servicing system also allows it to operate if the car has to be jacked up manually as it can still be utilised to remove the batteries.

The size has remained true to the specification throughout. Whilst significantly wider than a traditional Euro B segment vehicle, its length has remained well within the four metre maximum (Meadows, 2017) at every stage of the design process. Additionally, the width of the vehicle is comparable to contemporary WRC specification vehicles, at an approximate 1.8m wide (Evans, 2011).

The vehicles capabilities are significantly more advanced than the original specification. Thanks to the individual electric motors and computer controlled power delivery, the vehicle has the capacity for extraordinary straight line and cornering performance. The power of the vehicle is also significantly increased compared to the current WRC line-up (300 HP compared to 840 HP) (Evans, 2011). This is in a bid to build excitement around the sport with a return to the speeds of the legendary Group B era, albeit with a notably more safety conscious attitude. Thanks to the carbon fibre chassis used in the vehicles construction and stringent safety standards set by the FIA, it is far more resistant to impacts than its classic counterparts (Berman, 2015). Adding in the computer controlled power delivery, it is also far easier to drive. As a result, faster acceleration is more manageable, as this system affords the driver a much more predictable driving experience, especially in a performance setting (Kinsey, 2004).

As demanded in the original specification, the vehicle will be able to operate reliably and in a consistent manner in a wide array of environments. Graphene supercapacitors are much more temperature resistant than lithium ion battery cells and, therefore, are able to offer strikingly better performance in both extreme heat and cold. (Chaichi, 2020). Additionally, the all-wheel drive system employed in the vehicle will assist in ensuring maximum traction over all surfaces, making certain that it is not only capable of operating in extreme climates, but also of performing competitively.

The production methods of the vehicle are very well suited to the low volume figures required by the specification. The semi handmade nature of the carbon fibre parts guarantees minimal tooling, perfect for the made-to-order nature of the vehicle (Beecham, 2017). Such a production facility would also be more than capable of fulfilling the minimum homologation production number of 250. The manufacturing properties of the vehicle also facilitate ease of replacement of large sections in the event of an accident. Furthermore, the production method of bonding the body panels to the tub chassis will allow for the roll cage being affixed as one piece early in the construction process, reducing manufacturing time and allowing it to be integrated seamlessly into the vehicle, improving cabin space (Beecham, 2017).

Following research into the materials costs and manufacture of the vehicle, I believe that the cost estimated in the original specification (~£700,000) is a reasonable retail cost for the motorsport variant. As described in the specification of the outcome, I have estimated the final cost to be £750,000. This high price can be attributed to the exotic materials and labour intensive production methods for the chassis and body panels (Beecham, 2015). Additionally, the graphene supercapacitors and high-performance motors contribute to this high price tag (EV West, 2021), especially if a healthy profit margin is to be maintained.

Given that the technology required is currently available, the 2030 launch date is most certainly achievable. As the years pass, it is safe to assume that the range and efficiency of graphene supercapacitors will improve, only increasing their viability, if Moore's Law is to be believed (Britannica, 2019). Furthermore, it can be assumed that their cost will begin to decrease as their manufacturing processes become more efficient and common (Britannica, 2019).

As such, the final outcome has more than satisfied the requirement to make use of sustainable power and materials. The vehicle not only utilises recyclable materials, but also recycled materials. By using recycled carbon fibre for non-structural body elements, a great deal of raw materials and cost will be saved in comparison to using all-new carbon sheets. Moreover, the vehicle is powered by electricity: a renewable power source. The graphene supercapacitors are also more efficient and cleaner to recycle than lithium ion batteries, the current most popular technology (Future Bridge, 2020).

Overall, the final outcome has definitively succeeded in terms of satisfying the final brief. It has met or exceeded many of the criteria and comes in only slightly over the original predicted cost, thanks to deeper research into the costs of high performance electric motors (EV West, 2021).

Whilst even the homologation version is priced in supercar territory, the current performance car market has shown that enthusiasts are willing to pay very large amounts for specialist vehicles (Hagerty, 2021).

Market Awareness & Sustainability

Throughout the design process I have given a great deal of consideration to the vehicle's sustainability. From the alternative fuel powertrain, to recycled materials, sustainability has been at the forefront of the ideation process. The supercapacitor battery system not only allows for more controlled weight distribution but also a reduction in size, weight and an increased lifecycle (Graphene-Info, 2020). Utilising the graphene supercapacitor in this design will allow its development to be accelerated through the medium of motorsport.

Great care was taken to ensure that the vehicle is suitable for its target market continuously through each stage of the ideation and design process. From the built in lifting system, to the easy to access power train elements and ample room for helmet clad pilots, the vehicle is designed to be the ultimate in all-surface performance. This is further backed up by the four individual electric motors that send power to the wheels. In order to ensure maximum performance, they are individually controlled by a central module so as to imitate a dynamic limited slip differential (Chaichi, 2020).

The lifting system ensures that mechanics can comfortably work on the vehicle whilst reducing the amount of equipment that requires shipping along with the teams, thus saving time, money and reducing the overall carbon footprint of the sport (Edmondson, 2019). This is further enhanced by the portable solar powered chargers used to charge the spare supercapacitors. Using clean energy to charge the vehicles reduces the carbon deficit incurred during the production of the vehicle and raw materials, resulting in a significantly more environmentally friendly vehicle than those requiring a generator or the grid to top up the vehicle's cells (WWF, 2021).

Moreover, the composite materials that make up the vehicle's construction are without exception both motorsport oriented and sustainable, so as to completely fulfil the specification. The use of recycled plastic and composite for the interior, with the addition of carbon fibre for the body panels results in a car that meets the environmental requirements of the specification, without compromising performance or structural rigidity (MBFG, 2014).

Thanks to recent innovations, it is now possible to recycle carbon fibre (Fig 5) (Composite UK, 2021). This ensures that even if the body panels and chassis of the vehicle have to be taken out of commission, the material could still be used in other parts after the recycling process



Fig 5

(Composite UK, 2021). Thanks to this advancement, it is now possible for performance vehicles to make use of carbon fibre whilst remaining sustainable and further reducing their carbon footprint.

Conclusion

In conclusion, the final outcome has been highly successful in fully satisfying the original product design specification. The design has improved significantly since the original proposal, developing into the final outcome (Fig 6). By reflecting on and analysing my work at each stage of the ideation and realisation process, I was able to create the best final product possible within the deadline. Whilst some changes had to be made to produce the final outcome, it remained pleasingly true to the original idea and design specification.



Bibliography:

Beecham, M (2017) *Carbon fibre in car production – weighing up the benefits* www.just-auto.com/analysis/carbon-fibre-in-car-production-weighing-up-the-benefits_id176724.aspx (Accessed on 12/5/21, 20:11)

Berman, B (2015) <https://www.technologyreview.com/2015/08/10/72629/wheres-the-affordable-carbon-fiber-automobile/> (Accessed on 13/5/21, 15:11)

Britannica (2019) www.britannica.com/technology/Moores-law (Accessed on 12/5/21, 9:26)

Chaichi, A (2020) *A Solid-State and Flexible Supercapacitor That Operates across a Wide Temperature Range* [pubs.acs.org/doi/10.1021/acsaem.0c00636#:~:text=\(16%E2%88%9218\)%20Reduced%20graphene,%C2%B0C%20for%20supercapacitor%20applications](https://pubs.acs.org/doi/10.1021/acsaem.0c00636#:~:text=(16%E2%88%9218)%20Reduced%20graphene,%C2%B0C%20for%20supercapacitor%20applications). (Accessed on 9/5/21, 11:53)

Composite UK (2021) compositesuk.co.uk/composite-materials/properties/end-life-options#:~:text=Several%20companies%20now%20exist%20to,is%20active%20at%20small%20scale. (Accessed on 12/5/21, 10:27)

Evans, D (2011) www.espn.co.uk/f1/story/_/id/28395224/the-environment-pose-f1-biggest-challenge-2020s (Accessed on 9/5/21, 11:49)

Evans, D (2011) *WRC Preview: Tech Insight* Autosport – Vol 203 no.6. pages 60-61
United Kingdom: Haymarket Publications

EV West (2021) https://www.evwest.com/catalog/index.php?manufacturers_id=47 (Accessed on 11/5/21, 17:43)

Future Bridge (2020) www.futurebridge.com/industry/perspectives-mobility/supercapacitors-a-viable-alternative-to-lithium-ion-battery-technology/#:~:text=While%20a%20Supercapacitor%20with%20the,a%20Lithium%20Dion%20battery%20offers. (Accessed on 9/5/21, 11:44)

Graphene-Info (2020) www.graphene-info.com/graphene-supercapacitors (Accessed on 9/5/21, 12:31)

Hagerty (2021) www.hagerty.com/apps/valuationtools/market-trends (Accessed on 11/5/21, 18:02)

Kinsey, J (2004) *The Advantages of the Electronically Controlled Limited Slip Differential*
www.sae.org/publications/technical-papers/content/2004-01-0861/ (Accessed on 11/5/21, 11:14)

MBFG (2014) *The benefits of carbon fibre* www.mbfq.co.uk/blog/carbon_fibre.html (Accessed on 13/5/21, 19:54)

Meadows, J (2020) *Vehicle Design: Aesthetic Principles in Transport Design* pages 39-40
United Kingdom: Routledge

Rowswell, G (2019) *Which Motorsport Technology Has Changed the Course Of History?*
www.fastcar.co.uk/fast-car-news/which-motorsport-technology-has-changed-the-course-of-history/ (Accessed on 12/5/21, 12:21)

Within Lab (2015) www.withinlab.com/benefits/new_gravity.php (Accessed on 12/5/21, 14:27)

WWF (2021) <https://www.wwf.org.uk/updates/how-do-i-charge-my-electric-car-renewable-energy> (Accessed on 13/5/21, 16:39)

Images:

Fig 1: Aldridge, M (10th May 2021) *R4e VRED Side Render*

Fig 2: www.motoringresearch.com/wp-content/uploads/2018/05/1987-Ford-Sierra-RS500-Cosworth-Chassis-No1-rear.jpg (Cropped) (Accessed on 11/5/21, 17:51)

Fig 3: Aldridge, M (17th April 2021) *R4e VRED City Scene Render* (Cropped)

Fig 4: Aldridge, M (10th May 2021) *R4e VRED Double Studio Render* (Cropped)

Fig 5: compositesuk.co.uk/system/files/styles/slides-responsivebreakpoints_theme_gwstrap_small_1x/private/field/image/ELG%20Carbon%20Fibre%20Carbiso%20M%20and%20TM%20nonwovevn%20mats.jpg?itok=CcdlCSk4 (Accessed on 11/5/21, 19:51)

Fig 6: Aldridge, M (12th April 2021) *R4e VRED Studio Service Render*