Imperial Eco-Marathon: Gen III

A Compact Leap in Vehicle Design

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Shell Eco-marathon 2025

Abstract

This report presents the conceptualisation, design, development, testing, and production of Gen III, the 2025 prototype entry for the Shell Eco-marathon by Imperial Eco-Marathon (IEM). The vehicle represents a full ground-up redesign aimed at radical improvements in aerodynamic performance, weight reduction, and compact integration. The document explores the guiding principles, the simulation and validation methodologies, the innovation of structural and ergonomics, and the considerations of sustainability that underpin the design.

Figure 1: Gen III, the 2025 entry from Imperial Eco-Marathon, shown in its final form. The compact profile, fluid tapering, and dragon-inspired geometry reflect a design ethos where aerodynamic efficiency and visual identity converge.

1 Introduction

Imperial Eco-Marathon (IEM) has been a proud participant in the Shell Eco-marathon competition for multiple years, driven by a passionate team of engineers dedicated to pushing the boundaries of energy-efficient vehicle design. Over time, IEM has evolved from a small student initiative to a data-driven, innovation-focused program committed to excellence and continuous improvement.

The Shell Eco-marathon Prototype category challenges teams to design ultra-efficient vehicles that achieve maximum energy economy within strict technical and regulatory constraints, encouraging innovations in aerodynamics, materials, driver ergonomics, and sustainability.

For the 2025 competition, IEM has undertaken its most radical transformation yet: a complete ground-up redesign culminating in the Gen III prototype. Unlike its predecessors, Gen III is not an incremental upgrade to its predecessor; it is a complete redesign. Drawing from natural forms such as dolphins and mirroring the sinuous lines of a dragon — our team emblem — the vehicle's shape embodies both functional minimalism and aesthetic precision.

Compared to Gen II, Gen III is **30 cm** shorter, **20 cm** narrower, and **20 cm** lower, resulting in a **25%** reduction in frontal area and a **31%** reduction in overall vehicle mass. The vehicle achieves a drag area (CdA) of just **0.0334 m**^{2} and weighs under **30 kg**, marking a significant leap forward in IEM's lineage. The mechanical components of the car are expected to be optimised in further years potentially reaching 23 kg.

Pursuing a shorter vehicle concept diverges from the conventional approach seen in most Shell Eco-marathon prototypes, which typically feature long bodies and extended wheelbases to facilitate packaging and stable flow development. However, IEM identified several strategic advantages to a more compact design. First, a shorter car can be inherently lighter, as structural stiffness does not scale linearly with length. Second, a shorter wheelbase reduces the required steering angle, allowing for a narrower body and further drag reduction. Lastly, although short vehicles introduce challenges in maintaining smooth, attached flow, these can be mitigated through careful aerodynamic shaping, validated via extensive simulation and wind tunnel testing. Together, these benefits support the goal of minimizing drag and mass without compromising control or stability.

Sustainability principles have guided material selection, manufacturing processes, and end-of-life strategies — from minimising waste in CNC tooling to evaluating recyclable and bio-based alternatives for future iterations — reinforcing IEM's commitment to responsible engineering.

This report details the rationale, development, and testing of Gen III's major subsystems, including aerodynamic refinement, structural design, ergonomic optimization, and sustainability practices. It also presents lessons learned and outlines future research directions, highlighting IEM's continued journey toward energy-efficient vehicle innovation — where engineering meets identity, and performance meets purpose.

2 Data-Driven Evolution: Lessons, Philosophy, and Design Innovation

The development of Gen III was fundamentally shaped by the team's reflections on the Gen II platform. Although Gen II was a capable and reliable vehicle that successfully completed the 2024 Shell Eco-marathon, it revealed several limitations that offered critical opportunities for improvement. These lessons formed the foundation for Gen III's data-driven, purpose-built design.

From an aerodynamic perspective, Gen II demonstrated a drag area (CdA) of 0.0883 m^2, which, although acceptable, was higher than desired. CFD simulations and post-race analysis identified flow separation near the front wheel arches and a turbulent wake region caused by an abrupt rear taper. These findings directly informed Gen III's approach to flow shaping and wake management.

Structurally, Gen II's mass reached 44 kg without the driver — well above target. Post-event teardown revealed excessive safety margins and overbuilt structural members. These inefficiencies motivated a shift to a more material-efficient monocoque design for Gen III.

Ergonomically, Gen II's canopy and seating compromised driver visibility and packaging. Poor shoulder clearance and difficult ingress/egress prompted the use of a physical ergonomic test rig in Gen III's development to validate human factors from the outset.

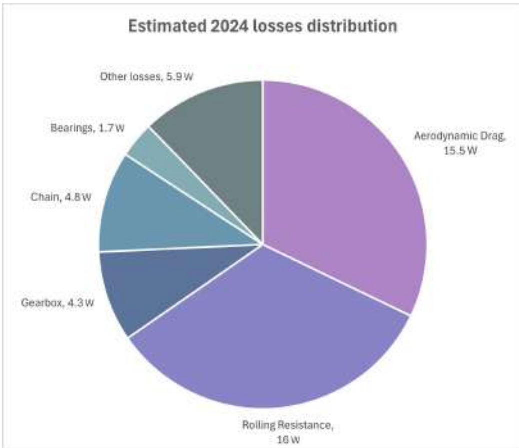


Figure 2: Breakdown of average power consumption in Gen II by resistive force.

To complement qualitative findings, telemetry and coast-down testing were used to decompose power losses in Gen II into major components. As shown in Figure 2, over two-thirds of power losses were controllable via shape and mass — confirming the team's decision to concentrate design effort on those areas.

- **Rolling resistance:** Motivated weight reduction, tyre selection, and ride height control.
- **Aerodynamic drag:** Justified investment in surface refinement and passive flow control strategies.
- **Minor losses:** Drivetrain inefficiencies led to optimised chainline geometry, gear meshing, and lubrication.

The result was a strategic reallocation of design effort, producing a 40% structural weight reduction and a halving of the drag area, ultimately reaching 0.0334 m^2 — well below the original 0.0440 target.

2.1 Design Philosophy and Conceptual Objectives

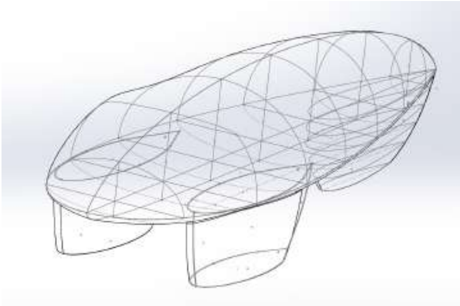


Figure 3: Early Gen III design concept exploring trade-offs between frontal area, driver visibility, and packaging.

Beyond pure technical refinement, the Gen III design was shaped by an underlying aesthetic concept: a fusion of compact power and controlled flow, drawing subtle inspiration from the aerodynamic elegance of marine life and the mythic symbolism of the dragon. The team's dragon-head emblem, paired with a sharp red-white-gray visual palette, informed not only brand identity but also influenced the visual cohesion of the vehicle — sleek, deliberate, and composed.

The outer form emerged from a tension between biological streamlining and mechanical restraint. The vehicle's silhouette reflects this union: a low-slung fuselage with refined tapering, tightly integrated wheel volumes, and a canopy shape evoking the spine of a coiled predator — aerodynamic efficiency imbued with symbolic intent.

Three central priorities guided the development:

1. **Aerodynamic Efficiency:** Minimise drag by reducing frontal area and refining surface curvature.
2. **Structural Lightness:** Improve the concept of a carbon fibre monocoque to eliminate redundant reinforcements.
3. **Driver Accommodation:** Design for a 1.55 m tall driver within SEM constraints for visibility, safety, and comfort.

These objectives introduced significant tradeoffs — e.g., minimising frontal area while ensuring helmet clearance, or compact packaging without compromising ergonomics. The solution was cross-functional collaboration which included the manufacturing of a rig to test the drivers ergonomics and guide the design.

2.2 Cross-Functional Collaboration and Agile Development

Weekly integration reviews between aerodynamics, structure, and human-factors teams enabled agile feedback cycles. For instance, advancing the hip point by 3 cm reduced canopy height, allowing smoother nose shaping without compromising drag or safety. This replaced traditional sequential design with parallelised decision-making, enabling early resolution of interdependencies and rapid convergence on a balanced solution.

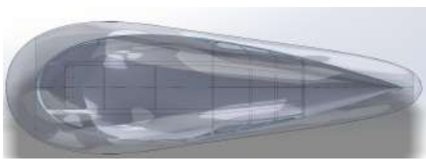
2.3 Design Outcomes and Corrective Implementation

Gen III reflects a deliberate evolution, directly shaped by past performance data and iterative testing:

- **Form factor reduction:** 30 cm shorter, 20 cm narrower and lower — slashing frontal area and surface drag.
- **Carbon monocoque:** Integrated shell architecture cut ∼14 kg versus Gen II.
- **Driver-centred cockpit:** Anthropometric modelling and a physical test rig delivered optimal visibility and ingress.
- **Tuned flow geometry:** A gentler rear taper and reshaped underbody delayed separation and reduced lift.

(a) Front view.

(b) Side view.



(c) Top view.

Figure 4: Comparison between Gen II and Gen III.

Together, these outcomes achieve:

- 50% reduction in drag area
- 14+ kg reduction in structural weight
- Full SEM ergonomic compliance for a 1.55 m driver
- Embedded safety structures within the monocoque

This process exemplifies not only technical innovation but also a maturing engineering culture — one that prizes evidence, iteration, and interdisciplinary coherence.

3 Aerodynamic Design and Optimization Using CFD

Minimizing aerodynamic drag was a central design priority in the development of Gen III. Drawing inspiration from natural flow forms and successful strategies from previous Shell Eco-marathon vehicles, the team implemented a rigorous CFD-driven workflow (illustrated in Figure 5 — from parametric geometry modeling to wind tunnel validation — to guide each design decision with data.

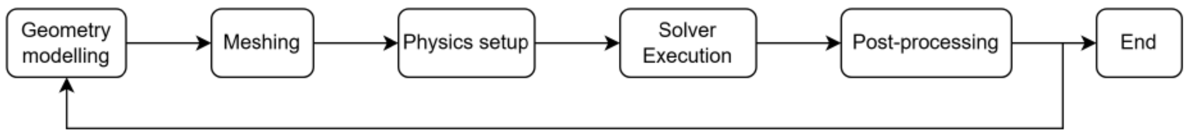


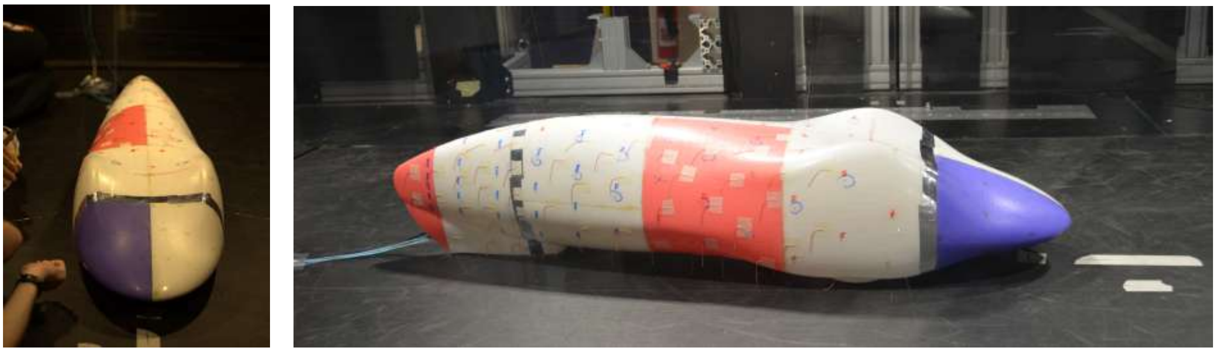
Figure 5: CFD analysis pipeline followed in StarCCM+.

3.1 Initial Design Development and Scale Model Validation

Early design iterations were evaluated not only for flow characteristics but also for visual coherence. The team explored a family of shapes that balanced functionality with symbolic impact — refining the canopy and rear taper to suggest forward momentum and controlled aggression. The dragon motif served as a thematic compass: bold yet balanced, compact yet dynamic.

Although the vehicle's aesthetic does not directly impact aerodynamic performance, the design philosophy emphasized that form and function need not be at odds. The final shape, while compact and CFD-validated, carries a distinct identity — a stealthy form that stands apart on the track.

We produced a 1:2 scale physical model of our earliest design and tested it in the 10' x 5' Imperial College London wind tunnel, validating our simulation fidelity with more than 100 surface pressure taps and a 60-probe wake rake.



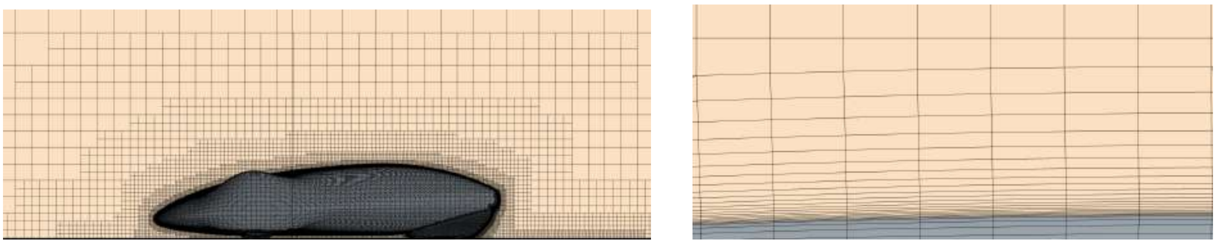
(a) Front view of the model in the Wind Tunnel.

(b) Detailed side view of the pressure taps and tufts for flow visualisation.

Figure 6: Scale model used for preliminary wind tunnel testing and validation.

3.2 CFD Setup and Meshing Strategy

All simulations were conducted in StarCCM+ using steady-state RANS equations. Meshes were generated using a trimmed core with prism layers to resolve the boundary layer. The domain extended five vehicle lengths upstream, ten downstream, and five on each side and above, minimizing inlet/outlet effects.



(a) General mesh around the Gen III car. **(b)** Detail of refined mesh around the body.

Figure 7: CFD mesh with detailed prism layers around the body surface.

Table 1: CFD Simulation Parameters

Parameter	**Value**
Fluid	Air
Inlet Velocity	5, 7, 9 m/s
Ambient Conditions	1 atm, 300 K
Turbulence Model	k-ω SST with Re-θ transition
Air Density	1.225 kg/m^3
Boundary Conditions	Moving ground, rotating wheels

3.3 Parametric Optimization Process

We controlled seventeen parameters in the vehicle geometry, covering overall dimensions, curvature, and stagnation locations. Over 50 major design variants were simulated, refining frontal shape, rear tapering, underbody clearance, and nose angle.

Figure 8: Representative aerodynamic design iterations showing progressive drag reduction (Iterations advance left to right).

Notably, we discovered that vehicle height and the placement of the front stagnation point had the most significant impact on both drag and vertical forces. By adjusting the stagnation point position and overall body curvature, we were able to manipulate the pressure distribution above and below the vehicle. In contrast to conventional racing vehicles, our goal was not to generate downforce, but rather to explore configurations that permitted slight positive lift, which can reduce rolling resistance at the extremely low speeds of Shell Eco-marathon. Importantly, we ensured that any lift generated remained within safe limits to preserve directional stability.

3.4 Drag Coefficient Determination and Interpretation

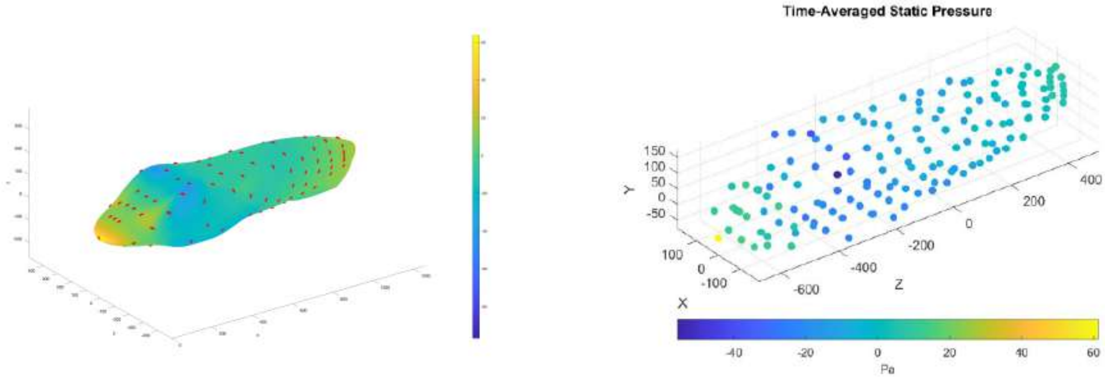
Aerodynamic efficiency was quantitatively assessed using the drag coefficient C_d, defined as:

$$C_d = \frac{2F_d}{\rho V^2 A} \tag{1}$$

Here, F_d is the total drag force, ρ the air density (1.225 kg/m^3), V the freestream velocity, and A the frontal area of the vehicle. Drag forces were extracted from CFD simulations in StarCCM+ via surface integration of pressure and wall shear stress over the entire vehicle body.

To validate the simulation data, a series of wind tunnel tests were conducted using a 1:2 scale model equipped with over 100 pressure taps and a custom 3D wake rake. This allowed for a direct comparison between simulated and experimental pressure fields — a crucial step in confirming both the accuracy of flow structures and drag predictions.

Analysis of these results confirmed that pressure drag remains the dominant contributor to total aerodynamic resistance, especially at the nose and rear taper. The CFD simulation showed excellent agreement with wind tunnel data in terms of pressure recovery and wake formation, affirming the accuracy of boundary layer modelling and surface pressure distribution.



(a) CFD surface pressure distribution (StarCCM+) with Wind tunnel probe location

(b) 3D point cloud from pressure probe data in wind tunnel

Figure 9: Comparison of simulated and experimental pressure fields used to validate aerodynamic performance and assess drag characteristics.

The final aerodynamic configuration achieved:

$$\boxed{C_d = 0.1002 \quad \text{and} \quad C_dA = 0.0334 \text{ m}^2}$$

This represents a 41% reduction in C_d and more than 50% improvement in C_dA compared to the previous generation, exceeding our original performance target of 0.044 m^2.

Key design features enabling this performance:

- Dolphin-inspired, smoothly tapering rear body to reduce flow separation.
- Internally integrated rear wheels to minimize wake generation.
- Controlled underbody ground clearance to optimize pressure distribution and minimize lift.

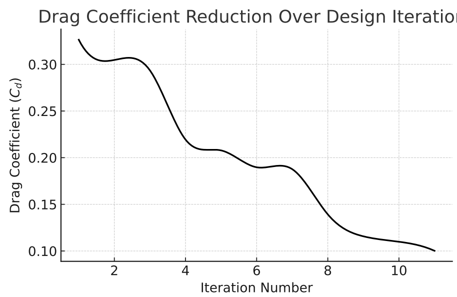


Figure 10: Drag coefficient trend over 11 major design iterations: from an initial C_d = 0.326 to final C_d = 0.100.

3.5 Flow Quality Assessment

We used wall shear stress and vorticity magnitude to assess flow separation and pressure recovery zones. Maintaining an attached boundary layer—particularly along the roof and diffuser—was critical for efficient flow reattachment and reduced wake drag.

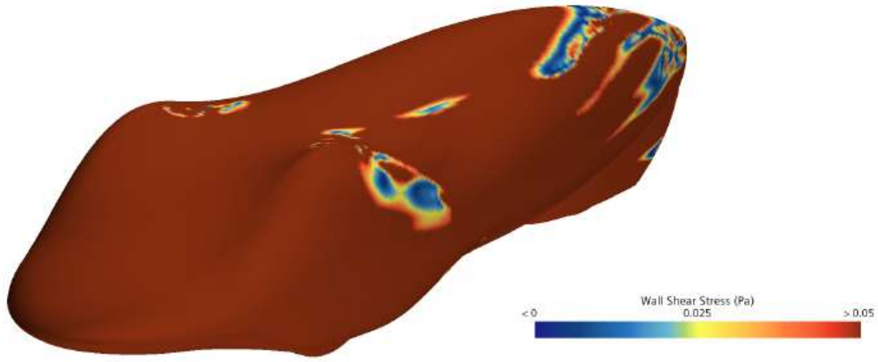
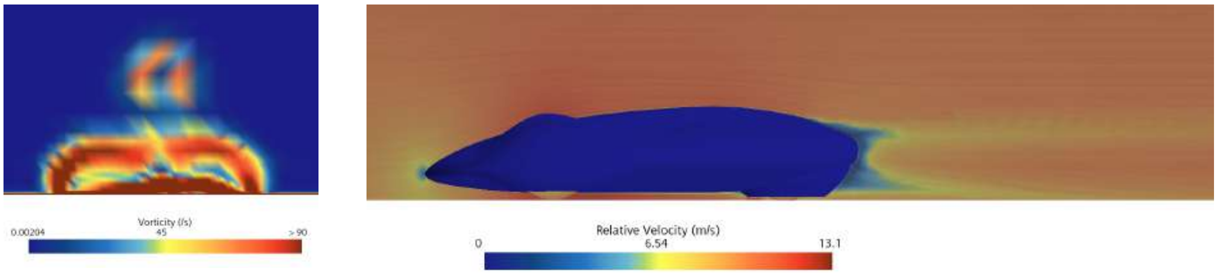


Figure 11: Wall shear stress map highlighting critical detachment regions.



(a) Vorticity in the wake of Gen III.

(b) Velocity field along the body of Gen III.

Figure 12: Vorticity and velocity fields showing wake development and recirculation zones.

3.6 Crosswind Stability and Wheel Design

We evaluated aerodynamic performance under side-slip angles up to 10°. Despite the absence of traditional wheel fairings, the final body shape was carefully sculpted to minimize flow separation and exposed frontal area around the wheels. By tapering the side profile and integrating the wheel volumes into the main body contour, we achieved favourable flow attachment even under crosswind conditions. This approach reduced parasitic drag without the structural or weight penalties associated with separate fairing components. Additionally, the front surface design provided natural recesses that doubled as ergonomic cutouts for driver arm clearance.

3.7 Performance Outcome and Benchmarking

The final design achieved a drag coefficient of $C_d = 0.1002$, translating to a frontal-area-adjusted $C_dA = 0.0334$, significantly surpassing our initial target of 0.0440. For comparison, our previous prototype had an estimated $C_d \approx 0.17$, highlighting a 41% reduction in drag through design optimization alone.

3.8 Conclusion

Through a high-fidelity CFD pipeline, wind tunnel validation, and a parametric design philosophy, we developed an aerodynamically superior vehicle body. Our bio-inspired and functionally optimized form achieves ultra-low drag while ensuring real-world stability and driver integration. These insights form a strong foundation for future iterations of the Gen III platform.

4 Structural and Ergonomic Design Integration

The structural and ergonomic design of Gen III was developed through a tightly integrated process aimed at achieving maximum stiffness, safety, and driver comfort while minimizing weight. Building on post-race evaluations of Gen II's overbuilt monocoque and inefficient load paths, Gen III optimises material usage and adopts a new design which more closely integrates with the driver interfaces.

Several structural architectures were evaluated in the conceptual phase. A hybrid spaceframe-aeroshell design was discarded due to the benefits of a monocoque in terms of packaging and stiffness to weight. Incorporating new core materials such as Nomex or aluminium honeycomb core were considered, but were discarded due to the manufacturing complexity and cost involved. The final carbon fibre–PVC foam core material layup was selected for its balance of manufacturing ease ensuring minimal defects, and its cost-to-strength effectiveness.

4.1 Monocoque Architecture and Iterative Structural Refinement

The multi-part construction of the Gen II's monocoque led to excessive usage of adhesive joints and therefore manufacturing overcomplexity and an inefficient use of material. The Gen III monocoque aimed to eliminate redundant connections to stride closer towards a unibody design. The final design resulted in a structural weight reduction exceeding **8 kg** alongside significant improvements in stiffness to weight ratios and crash energy management.

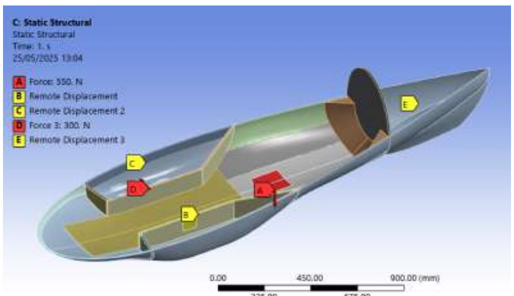
Finite Element Analysis (FEA) performed in **Ansys** was pivotal throughout the iterative design process. The model uses the Composite PrepPost (ACP) module to accurately define the carbon fibre layups. The foam cores were modelled as solid beam elements, and bonded to the shell elements to ensure transfer of load across the whole composite structure. This modelling method was applied to Gen II, which allowed physical testing to calibrate simulation results and true deflections.

Multi-criteria analysis (MCA) was used based on five critical parameters obtained from FEA, with a weighted average 'performance points' (PP) to compare between iterations. This ranges from the safety factor, weight, and various deflections that impacts vehicle dynamics and aerodynamics. Based on the MCA, early design iterations (V1 to V3) managed to improve the performance of Gen II by a 264%, by using a similar 'structure-**on**-shell' philosophy except with significantly lower weights and topology inspired optimisations. However, physical testing highlighting long egress time from the narrow driver compartment. This guided a transition to a 'structure-**in**-shell' philosophy in V4.X, where the two longitudinal panels were removed, and foam core was instead added to the layup of the shell. This initially led to two critical issues:

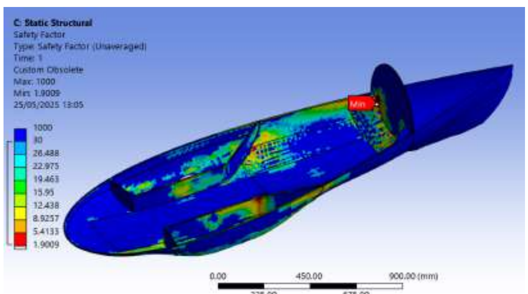
- MCA calculated PP was reduced by 60% from V3 due to increased weight and greater deformations
- Excessive transverse deflection of the vertical sandwich panel for the steering uprights

The latter was the more critical issue, as under steering loads, deflections exceeded **6 mm** in design iterations V4.3 and V4.4, compared to **3 mm** in V3. This was caused by increased torsional and shear deformation in the centre reinforced section and increased stress concentrations around the firewall bulkhead. A beam could not connect the two panels to add support, as it would negatively impact the egress time.

To address these challenges, additional structural elements and design changes were introduced. This included a triangular foam wedge functioning as structural support and an ergonomic driver headrest, and reduced height of the panels which the steering uprights are mounted to. This combination in the final V4.7 reduced lateral deflections down to **3.2 mm**, and improves MCA performance back up by 30%, representing double the performance of Gen II. Final safety factor under static loading was **3.6**, and **1.9** under steering, representing an ambitious drop from the excessively high S.F of Gen II at 4.2 and 3.0.

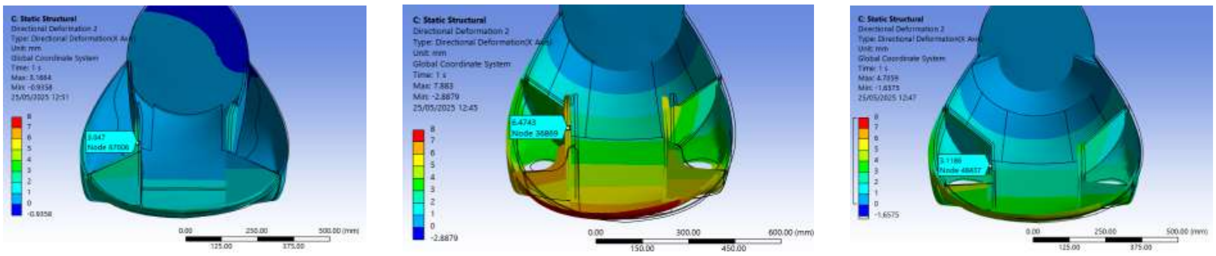


(a) Loads and B.C applied



(b) Safety Factor of Monocoque

Figure 13: Applied static & steering loads and contour plot of safety factors



(a) V3 **(b)** V4.4 **(c)** V4.7

Figure 14: Structural refinement to minimise steering panel deflections across Gen III iterations: V3 (left) possessed issues with driver egress; V4.4 transitioned to new design philosophy by having uniform core thickness across the centre section; V4.7 achieved appropriate deflections by adding foam wedge and reducing panel height.

The firewall core thickness was also evaluated, with a **15 mm** thickness outperforming **10 mm** variants in reducing lateral and vertical deflections. Additionally, lowered rear frame attachments points contributed to counteracting deformation effects.

0/90 degrees fibre orientations aligned longitudinal to the car were used across the main structures. This was deemed appropriate given the overall directions of principal stresses. As the skin was only two plies, isotropic layups would reduce stiffness and strength in the longitudinal direction, leading to excessive bending.

Critical load regions—including the **lap joints** between panels and **rear bulkhead**, were reinforced in manufacturing with extra plies in fibre orientations, informed by local principal stress distributions. **Harness and subframe mountings**, were not explicitly modelled, however reinforcement plies strengthened the adhesive bond of stainless steel bigHead(c) inserts. This method creates robust mechanical interfaces without compromising the monocoque's structural integrity.

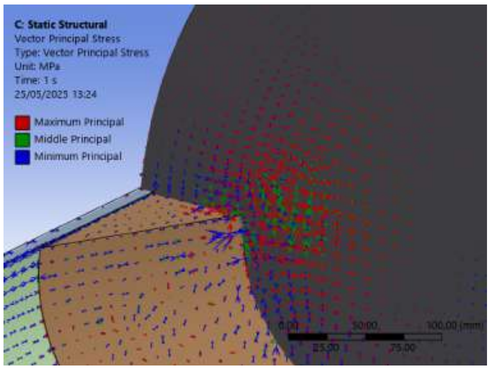


Figure 15: Example of principal stress directions within the site of minimum S.F, indicating choice of local fibre orientations to match max/min principal stress directions.

4.2 Material System, Manufacturing, and Validation

The monocoque was manufactured via vacuum infusion using **210 gsm 2x2 twill weave carbon fibre** skins paired with a **5-10 mm closed-cell PVC foam cores**, striking a balance between stiffness, impact resistance, and manufacturability.

Layup thickness varied from **2–3 plies** in the primary structure, to **5 plies** at critical points such as seatbelt anchorages and composite joints. A post-cure cycle following resin infusion enhanced the laminates glass transition temperature, improving long-term stiffness retention and thermal stability.

Load case simulations verified compliance with Shell Eco-marathon safety standards, with peak stresses and displacements remaining within acceptable limits and factors of safety exceeding 1.9 across all critical regions.

Manufacturing followed a controlled workflow emphasizing tooling precision, consistent resin infusion, and stringent post-curing protocols. The final monocoque achieved a mass of **5.0 kg** meeting ambitious weight targets without sacrificing mechanical performance.

Figure 16: Monocoque layup in progress, showing precise positioning of carbon fibre

4.3 Driver Ergonomics Validation and Feedback Loop

Recognizing the direct impact of structural design on driver comfort and safety, ergonomics were embedded early in the design process. The cockpit was optimised for a 1.55 m tall female driver, minimising frontal area while ensuring adequate clearances and visibility through digital mannequin simulations.

A physical cockpit test rig was fabricated based on the V3 reinforcement design, featuring adjustable shoulder supports, steering position, and pedal box configuration. This rig enabled thorough evaluation of ingress/egress timing, sight lines, reachability, and overall comfort under realistic driver postures.

(a) Laying down fitting test. **(b)** Head clearance check.

Figure 17: Driver test rig used for validating seating posture, visibility, and control ergonomics..

The integration of ergonomic features such as lowered shoulder supports and sculpted canopy slopes not only improved comfort and visibility, but also contributed to the vehicle's coherent exterior form, particularly for positioning of the windows. These changes aligned functional needs with the visual language of Gen III's low-profile aerodynamic shell.

Egress testing demonstrated compliance with safety regulations, achieving an average exit time of **7.8 seconds**, well below the **10-second** threshold. Harness mounts were structurally integrated along verified stress paths and padded at critical contact points to enhance driver comfort during extended operation.

4.4 Summary and Lessons Learned

The integrated structural and ergonomic development approach delivered a monocoque platform that successfully balances light weight, stiffness, safety, and driver-centred design. Iterative FEA underscored the critical importance of reinforced centre sections and firewall core thickness in mitigating twist and excessive deflections, while the driver rig validated comfort, visibility, and emergency egress.

Collectively, these efforts produced a repeatable, high-performance chassis architecture that confers a competitive advantage and satisfies all Shell Eco-marathon technical and human factors requirements.

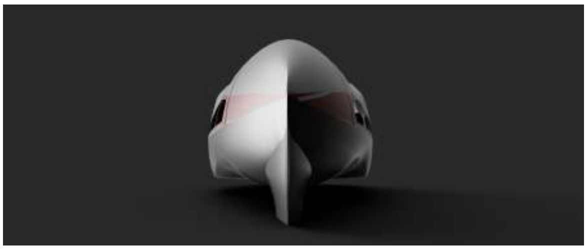
Figure 18: Final monocoque shell prior to system integration.

5 Vehicle photographs & drawings

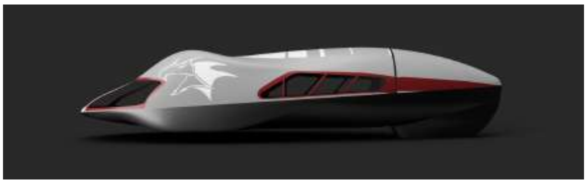
(a) 3/4 Front Perspective View

(b) 3/4 Rear Perspective View

(c) Direct Front View

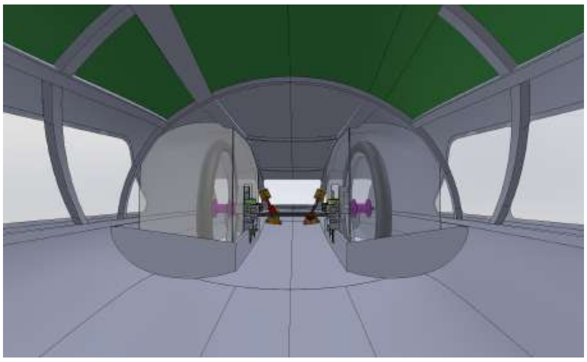


(d) Direct Rear View



(a) Side View.

(b) Top View.



(c) Cockpit View.

Figure 19: Renderings and technical views of Gen III.

6 Team Structure and Timeline

The development of Gen III was a coordinated, cross-functional effort involving over 30 student engineers at Imperial College London. The project was structured around eight specialised sub-teams, each tasked with the ownership and execution of a core subsystem, while a leadership and integration team ensured system-level alignment throughout the design and build process.

6.1 Organisational Structure

The IEM team is organised into the following sub-teams:

- **Aerodynamics:** Responsible for the external geometry of the vehicle, CFD simulation, wind tunnel testing, and drag minimisation strategies.
- **Composites (Monocoque):** Led the structural design and manufacturing of the carbon fibre chassis, including FEA and layup strategy.
- **Conventional Mechanics:** Developed steering, suspension, braking, and drivetrain mounting

systems.

- **Simulation (Race Strategy):** Handled performance prediction, powertrain modelling, and energy management strategy through vehicle dynamics simulation.
- **Electronics:** Designed and implemented telemetry, sensor systems, and electronic control units.
- **Battery:** Managed battery cell testing, packaging design, thermal management, and integration.
- **Research and Development (R&D):** Investigated new technologies such as lubricants, low-resistance bearings, and novel manufacturing methods to improve efficiency.
- **Business:** Handled sponsor engagement, financial planning, event preparation, and media content.

Each sub-team operated under a designated Team Leader, who met biweekly with the Technical Director and Team Principal to review progress and resolve inter-team dependencies. Shared integration members ensured consistency between systems and helped manage shared interfaces (e.g., monocoque mounting points, wiring harness routing, and aerodynamic-structural overlaps).

This decentralised but coordinated structure allowed for rapid iteration within subsystems while preserving overall program alignment.

6.2 Project Timeline and Development Phases

The Gen III vehicle was developed across four main phases over a 16-month timeline. Each phase focused on specific deliverables, with staggered design and manufacturing start times to match subsystem complexity and dependency.

Task	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Aero & CAD																	
Lit. review & benchmark	■																
CFD setup & baseline		■	■														
Aero shape opt. (CFD)				■	■	■	■	■	■	■	■						
CAD modelling aero parts		■	■	■	■	■	■	■	■	■	■						
Wind tunnel prep										■	■	■	■				
Wind tunnel test													■				
Concept Dev. (Non-Aero)																	
Struct. design & FEA setup							■	■	■								
Ergonomics & test rig							■	■	■								
FEA refinement & updates										■	■	■	■				
Driver ergonomics test										■	■						
Elec/control system design										■	■	■	■	■	■		
Full-Scale Simulations																	
Full vehicle CFD & thermal												■	■				
Full vehicle FEA & modal												■	■				
Manufacturing & Testing																	
Tooling & mould fab														■	■	■	
Composite layup & inspection														■	■	■	■
Sub-assembly prep														■	■	■	■
Component bench test														■	■	■	■
Durability & fatigue test															■	■	■
Vehicle Integration & On-Track																	
Vehicle assembly																■	■
Systems testing															■	■	■
On-track testing																	■
Data logging & feedback																■	■
Documentation & Reporting																	
Report drafting																	■
Presentations & visuals																	■
Final report review																	■

Figure 20: Project development timeline showing subsystem design, manufacturing, and integration phases.

- **Phase 1 – Aerodynamic Concept Development (Jan–Jun 2024):** Early CFD studies and CAD iterations began in January 2024. The external body shape was refined through over 50 simulation loops, culminating in a 1:2 scale model tested in a wind tunnel at the end of January 2025.

- **Phase 2 – Full-System Design (Jul–Dec 2024):** From July 2024, all teams began coordinated design efforts. CAD integration, structural FEA, battery packaging, and electronics system planning were developed in parallel. Full-scale CFD continued through this period. A design freeze occurred in mid-December.
- **Phase 3 – Manufacturing and Testing (Jan–May 2025):** Monocoque layup and subsystem fabrication commenced in early February. Assembly and bench-level testing of electronics, drivetrain, and battery were completed in April, followed by partial integration and structural quality assurance.
- **Phase 4 – Integration, Validation, and Documentation (May 2025):** Full vehicle integration was completed in early May. Track testing for handling validation and energy consumption profiling occurred mid-May, followed by final documentation and award submission.

6.3 Key Coordination Strategies

Given the high level of parallel development, the team employed several key strategies to maintain coordination:

- Weekly internal subteam meetings and shared progress dashboards for asynchronous updates.
- Biweekly leadership syncs with the Technical Director and Team Principal to resolve system-level issues.
- Version-controlled CAD and simulation repositories with milestone-based freeze points.
- Shared integration liaisons for aerodynamic-structural, structural-electrical, and electronics-powertrain overlaps.

This structured approach enabled Gen III to be developed on time, within budget, and in alignment with Shell Eco-marathon regulations — all while preserving the flexibility to incorporate innovative design ideas.

7 Sustainability and End-of-Life Considerations

Sustainability considerations were embedded into every stage of Gen III's design and manufacturing process. While carbon fibre remained essential to achieving the vehicle's structural and aerodynamic targets, the team adopted a lifecycle-informed approach to minimise waste, reduce energy inputs, and facilitate reuse and recycling at end-of-life.

It is important to note that one of the main objectives of Gen III is to build a solid base from which the car can be optimised and upgraded. From this point of view, the energy spending and material cost for this year need to be seen as spread throughout the following years in which the vehicle base will be reused.

7.1 Material Selection and Waste Minimisation

To limit composite waste, all carbon fibre fabrics were precision-cut using CNC drag-knife automation. This process enabled tighter nesting, yielding a 15% reduction in offcuts compared to manual methods. Ancillary materials such as infusion mesh and peel ply were sourced from UK-based suppliers to lower embedded transport emissions and support local industry.

Reusable silicone vacuum membranes were introduced for select non-structural components, replacing disposable bagging film. In parallel, composite layup sequences were digitally optimised using SolidWorks Composite Design and validated via small-scale preforms to reduce material overuse during full-scale production.

7.2 Manufacturing Impact Reduction

The team implemented several energy-saving measures during composite processing. The entire monocoque was cured at ambient temperature accepting the longer curing time but reducing the energy footprint by more than 25% compared to high-temp prepreg cycles. VOC exposure was also reduced by switching to low-emission epoxy systems and implementing closed-container resin mixing protocols.

7.3 Disassembly and Reusability

Gen III was designed with maintenance and end-of-life recovery in mind. Critical subsystems such as the rear drivetrain assembly, suspension mounts, and steering system are mounted using detachable aluminium inserts and bolted flanges, enabling easy disassembly without structural degradation. The rear subframe, constructed from 6082-T6 aluminium, is fully removable and intended for reuse across multiple vehicle generations.

7.4 End-of-Life Strategy

While thermoset carbon composites are challenging to recycle, the team initiated a pilot study into mechanical reclaiming methods for offcut regrinding and explored potential partnerships with composite reclamation networks in the UK. All structural foam cores (PVC) are solvent-free and recyclable via thermal depolymerisation.

The team has also committed to evaluating natural fibre composites such as flax and basalt fibre for secondary body panels and fairings in future iterations. These materials offer improved biodegradability and lower embodied energy while maintaining acceptable mechanical properties for non-critical areas.

In parallel with the Gen III vehicle development, the team has undertaken research into a novel bio-based lubricant as part of its commitment to sustainable propulsion systems. This initiative explores the formulation and performance benchmarking of a synthetic lubricant derived from renewable feedstocks. Though early in its testing phase, the bio-lubricant is intended for application in the drivetrain system, with the goal of reducing environmental toxicity, improving biodegradability, and lowering dependence on petrochemical-based fluids. The lubricant project is submitted separately under the Shell Eco-marathon Sustainability Award, and complements the Gen III platform's emphasis on end-to-end lifecycle responsibility.

8 Technical Feasibility and Manufacturability

The Gen III chassis was designed not only for performance but also for manufacturability under realistic student team constraints. By adopting a simplified tooling architecture, low-temperature processing, and modular subsystem design, the team ensured that all critical components could be fabricated and assembled in-house with high repeatability.

8.1 Composite Layup and Tooling Strategy

The entire body was produced using CNC-machined MDF moulds coated in PVA release film and sanded to 400 grit for surface finish. The tooling approach allowed rapid turnaround while maintaining dimensional accuracy. The layup was conducted using dry carbon fibre and a closed-cell PVC core, followed by vacuum-assisted resin infusion.

A sacrificial jig was developed to align critical inserts, ensuring repeatable mounting for suspension and steering systems. The total composite mass was reduced to under 9 kg due to careful ply tailoring and core placement.

8.2 Modular Subsystem Integration

Subsystem interfaces were standardised using bonded aluminium inserts, allowing for easy removal and replacement of components. This modularity not only reduced manufacturing complexity but also facilitated subsystem testing and validation prior to final integration.

8.3 Fabrication and Quality Control

All composite work, machining, and bonding were conducted in very close collaboration with one of the Team's main partners to retain almost full process control. Critical dimensions were verified using a laser coordinate system, and destructive test coupons were used to validate mechanical properties against simulation results.

In order to create the inserts for the steering uprights, a jig was 3D printed using the full vehicle assembly to define hole positions. Following the locations of the jig, drilling was done by a hand drill in an increasing succession of 5mm to 8mm to 10mm. Then the inserts were manufactured leaving an extra mm comparing with foam thickness to account for carbon thickness. This is such that when the mounting bolts for the steering uprights are tightened, the foam of the reinforcements is not crushed, preventing delamination and structural failure.

9 Risk Management and Iterative Validation

Risk mitigation was a cornerstone of the Gen III design strategy. By identifying potential failure points early, validating subsystem performance independently, and using simulation-in-the-loop design, the team minimised the likelihood of integration or operational issues.

9.1 Subsystem Isolation and Pre-Testing

Each major subsystem (braking, steering, powertrain, monocoque) was validated independently through benchtop testing and simulated loads. For example, the rear axle was tested with a $2.5\times$ safety margin for torque loading, and the harness mounting points were loaded with a 1500 N static test.

9.2 Digital Twin and Simulation Integration

A digital twin of the entire vehicle was created in SolidWorks and integrated into Ansys and StarCCM+ environments. Structural deflections, aerodynamic sensitivities, and load propagation were analysed before any physical manufacturing, reducing trial-and-error iterations.

9.3 Validation Through Prototyping

Full-scale subassemblies were prototyped using scrap layup materials to validate bonding sequences and assembly order. A 1:2 scale wind tunnel model of Gen III was tested at 18 m/s to validate CFD predictions, and coast-down tests on Gen II were used to benchmark expected improvements.

10 Impact and Future Outlook

The development of Gen III represents more than an isolated competition entry. It reflects a shift in the team's design culture — toward first-principles thinking, continuous validation, and systems-level integration.

The methodologies refined during this cycle — including CFD/FEA co-development, driver-centric design loops, and modular wind tunnel prototyping — will serve as blueprints for future projects. Beyond the competition, they offer educational and research value in the context of lightweight vehicle structures, sustainable composites, and aerodynamic testing.

Looking ahead, IEM is committed to:

- Exploring bio-based structural materials for non-critical components
- Expanding use of digital twins for real-time performance validation
- Publishing findings in open-access formats to contribute to the Shell Eco-marathon design community

Gen III demonstrates that high performance can coexist with clarity of purpose and disciplined engineering. As the team advances to future vehicle platforms, the lessons and culture of this project will continue to shape how we design, build, and test energy-efficient transport.

More details of the Gen III CFD simulations, wind tunnel test, and manufacturing can be seen in this video: https://youtu.be/2qgP-NwwNpU.