Smarter wheels: How multi-physics optimization is shaping the future of automotive design

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In the rapidly evolving field of automotive engineering, designing road wheels is a complex challenge that combines aesthetics, performance, and efficiency. At the 2025 NAFEMS World Congress, a collaborative project involving Nissan Technical Centre Europe, RBF Morph, and the University of Rome "Tor Vergata" presented a cutting-edge methodology that integrates styling, structural integrity, and aerodynamic performance through multi-physics optimization. This approach centres on advanced mesh morphing technology, which is enabled by rbfCAE [1], the latest platform developed by RBF Morph.

Engineering meets aesthetics in the EV era

In the age of electric vehicles (EVs), every gram saved, and every bit of aerodynamic resistance reduced counts. As one of the most visible components of any vehicle, wheels play a key role in mechanical performance and in branding and visual appeal. Electric vehicles place greater demands on wheels than ever: they must be lightweight for extended range, strong enough to withstand varying road conditions, and designed to minimize aerodynamic drag. Meeting these competing demands requires a comprehensive design approach, which is exactly what this research provides.

The study combines simulation tools like finite element analysis (FEA) and computational fluid dynamics (CFD) in a unified workflow. This enables real-time performance feedback and iterative design updates. Mesh morphing with radial basis function (RBF), a technique that applies fluid and continuous shape transformations directly to simulation meshes [2, 3] eliminates the need for traditional remeshing.

A legacy of innovation - the 50:50:50 paradigm

The foundations of this project were laid over a decade ago with the introduction of the 50:50:50 approach [4]: 50 shape variants, 50 million cells, completed in 50 hours. This methodology remains a key part of optimization, particularly as it transitions into AIsupported frameworks. The same principles of high automation, fidelity, and speed underpin the multi-physics workflow used in this study.

This concept has evolved beyond its original scope and now serves as a precursor to reduced-order modelling (ROM) and AI-based design tools. The ability to swiftly produce a substantial dataset of high-fidelity simulations is essential for training surrogate models and interactive dashboards.

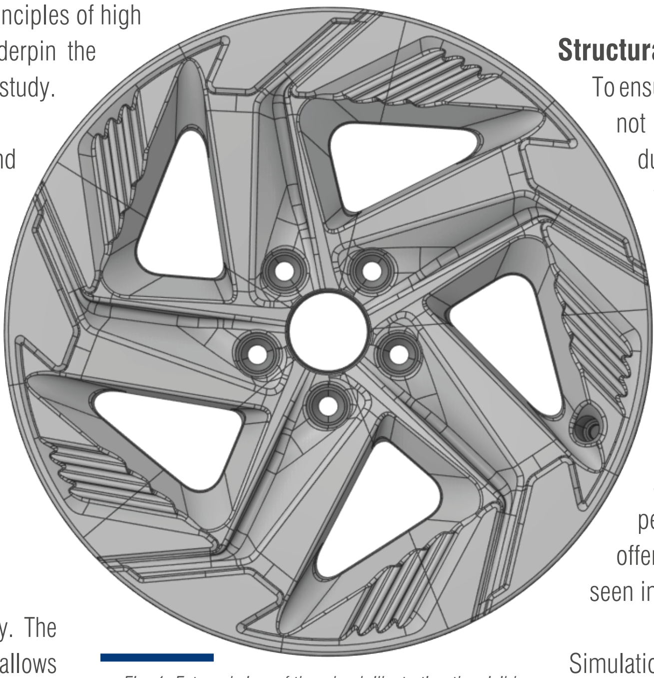

Fig. 1. External view of the wheel, illustrating the visible side that was kept fixed during optimization.

Building the multi-physics workflow

Styling requirements

Wheels define a vehicle's personality. The proposed optimization pipeline allows designers to bring their vision to life without compromising on structural or aerodynamic performance. The rbfCAE platform makes it possible to preserve aesthetic constraints, like spoke curvature or rim contours, while simultaneously modifying geometry for engineering benefits. Fig. 1 shows the outer surface, which corresponds to the visible side of the rim. This was kept fixed throughout the process to preserve its distinctive style, while optimization focused on the inner side of the wheel.

Design and engineering teams can interact through a shared workflow where domain-specific KPIs (key performance indicators) prompt targeted changes, and the impact of each change can be viewed immediately within an integrated visualization environment. This facilitates an informed, iterative process of convergence between CAD styling and CAE validation.

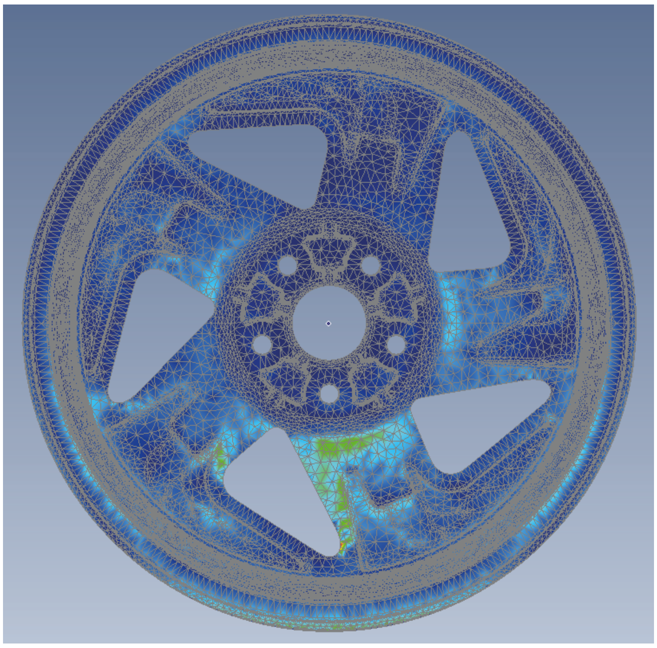

Fig. 2. Von Mises stress results for the baseline wheel configuration.

Structural performance

To ensure that any design modifications would not compromise the product's strength, durability, and impact resistance, a finite element analysis (FEA) was performed using Simcenter Nastran [5]. The wheels were modelled using an AlSi7Mg0.3 aluminium alloy and meshed with second-order tetrahedral elements.

The basic model, consisting of around 260,000 elements, revealed a peak stress well below material limits, offering room for optimization, as can be seen in Fig. 2.

Simulation conditions aligned with virtual certification standards, including static radial load tests, fatigue, and drop tests. The optimization workflow focused on one of the most demanding loading scenarios to ensure structural robustness under worst-case conditions.

Aerodynamics

CFD simulations were performed using HELYX software [6] on an AeroSUV model [7] with the wheel design being considered in this study, in order to measure airflow around the wheel and vehicle body. Note that the estimation of the aerodynamic effect is intended solely for the validation the proposed workflow. For confidentiality reasons, an AeroSUV body was used in place of the original vehicle geometry. The analysis used a steady-state RANS model with the k-ω SST turbulence formulation. The wheels were modelled using the multiple reference frame (MRF) approach to simulate rotation, with over 60 million cells per configuration. This aerodynamic evaluation was crucial in reducing drag and improving the vehicle's overall efficiency.

The use of the arbitrary mesh interface (AMI) method to enable more detailed transient simulations was also explored. Although it was not implemented in this study, the AMI method paves the way for future dynamic evaluations, such as driving simulations with rotating wheels.

Optimization strategies: parametric vs. evolutive

Two optimization routes were explored using the rbfCAE platform:

- Parametric morphing: Shape changes were controlled by user-defined variables, as previously described [8, 9]. Specific internal regions of the rim were offset to ensure compliance with minimum thickness requirements while preserving external styling features. Fig. 3 shows the rbfCAE platform setup for this case. This approach enabled precise tuning of performance attributes.

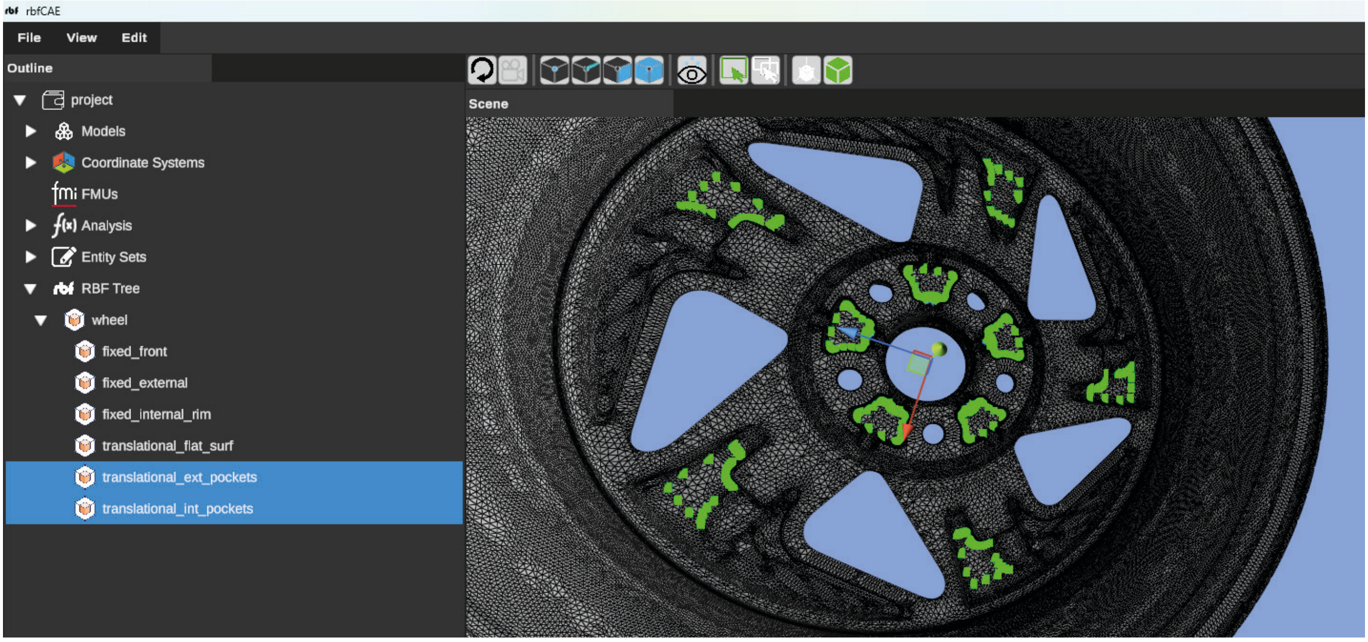

Fig. 3. rbfCAE platform setup for parametric mesh morphing.

- Biological growth method (BGM) morphing: Inspired by how bones and trees grow under stress, this method modifies geometry based on von Mises stress fields [10, 11]. Regions under less stress are thinned out and high-stress areas retain more material. This process yields organic, performance-driven shapes.

The parametric morphing approach is ideal for design studies that require full geometric control and strict style constraints. By contrast, BGM morphing offers a self-regulating mechanism that allows the geometry to adapt naturally to stress.

Case study: from simulation to results

Two optimization strategies were applied to an 18-inch production wheel. A structural analysis revealed that, while maintaining safety, parametric morphing slightly increased peak stresses. Conversely, the BGM design reduced stress concentrations. Both approaches reduced the wheel's mass by 400g.

The optimized designs were then integrated into a complete AeroSUV model and tested at 140km/h in open-air conditions. Table 1 summarizes the differences in drag and lift values, which were analysed to understand their impact on the vehicle's overall aerodynamics. Fig. 4 illustrates this by showing a comparison of the vortex structure (Q) and the 25,000 iso-surface distribution.

Configuration	FEMFAT WELD method	Von Mises stress (MPa)	Drag coefficient	Lift coefficient
Baseline	14.1	78.1	0.302	-0.013
Parametric morphing	13.7	81.3	0.304	-0.025
BGM morphing	13.7	75.9	0.305	-0.021

Table 1: Comparison of results between baseline and morphed configurations.

Although there is a slight increase in drag, the increased downforce and reduced mass could result in significant performance improvements, particularly for EVs that rely on regenerative braking and low rolling resistance.

rbfCAE: the engine behind the innovation

The rbfCAE platform enabled design changes to be seamlessly integrated into the FEA and CFD simulations. Avoiding remeshing significantly reduces the time required for each iteration. Thanks to its automated workflow manager, parametric tree setup, and connectors to solvers such as Simcenter Nastran and HELYX, the platform is the perfect tool for high-fidelity, cross-domain optimization.

The morphing tree structure enabled hierarchical and reversible modifications, supporting both global design changes and localized refinements. Each branch of the tree represented a parametric dependency, enabling engineers to trace and refine every transformation.

From morphing to real-time optimization

A clear path has been outlined for integrating reduced order models (ROMs) and artificial intelligence (AI) into the workflow. RBF Morph has already demonstrated these capabilities in the automotive field by enabling real-time geometry manipulation through interactive design dashboards and VR tools [12].

Other examples include using ROMs to optimize the aerodynamics of a cyclist's helmet [13] and developing a VR-based aircraft design environment [14]. In the latter example, mesh morphing combined with real-time feedback significantly accelerated the design loop.

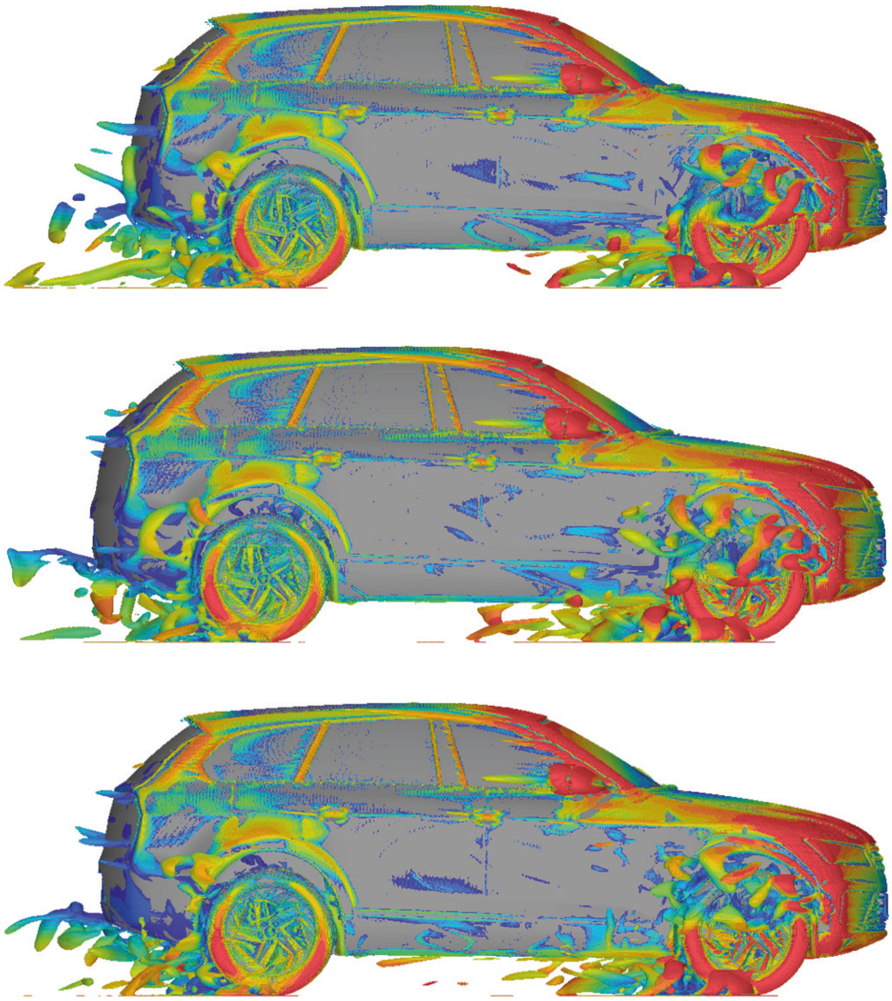

Fig. 4. Vortex structure (Q): 25,000-iso surface distribution, coloured by mean velocity, for the baseline (a), parametric-morphed (b), and BGM morphed (c) wheel configurations.

Conclusion

This work sets a new standard for automotive wheel design, facilitating collaboration between engineers and designers via a digital, multi-physics platform. By integrating simulation, mesh morphing, and optimization into one process, we demonstrated how to optimize performance, efficiency, and aesthetics. As vehicles continue to evolve, especially toward electrification, tools like rbfCAE will be essential for overcoming new design challenges.

The future of automotive design is lighter, smarter, and more integrated. It starts with the wheels.

RBF Morph, the University of Rome "Tor Vergata", and Nissan jointly presented this pioneering work at the 2025 NAFEMS World Congress, showcasing their shared vision for an integrated, simulation-driven approach to automotive design.

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