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DM3803 Major Project

BSc Product Design Engineering - Level 3 - Brunel University London

Major Project Report

Custorim Interchangeable Rim System

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Introduction

During my internship at CMS, a prominent rim manufacturer based in Turkey, I was fully immersed in the intricacies of cast rim manufacturing.

This experience spanned various facets, including OEM and aftermarket wheel design, client interactions with renowned car manufacturers, and the detailed processes of manufacturing and marketing. This exposure provided me with a unique vantage point to observe and identify potential engineering, design, and manufacturing opportunities along with specific challenges that could be addressed.

Issues I Have Faced

A significant challenge in cast alloy wheel manufacturing is the inherent limitation posed by the casting process itself. As the liquid aluminum alloy cools within the mold, it often develops porosity or inconsistencies, which fundamentally restricts the design flexibility. These material weaknesses prevent the creation of thinner, lighter, and more resource-efficient wheels. Additionally, the need to incorporate specific design constraints such as draft angles, minimum thickness requirements, symmetry, and soft edges often complicates the design process. These restrictions not only stifled my creative aspirations as a designer but also hampered the performance capabilities of the final products.

Motivation and Action

Motivated to overcome these limitations, I envisioned a system that integrates the robustness and lightweight properties of forged magnesium or aluminum alloys with the versatility of UV-resistant coated, 3D printed ABS plastic spokes. This combination aims to maximize design freedom and performance efficiency without the structural compromises typically associated with cast wheels.

The proposed system utilizes a simple, yet highly effective, user-friendly attachment mechanism integrated into the base rim, which is crafted through precise CNC machining and forging processes. This not only enhances the rim's functional attributes but also ensures easy customization of the wheel's appearance through interchangeable spokes.

Conclusion

This project represents a synthesis of my skills in design engineering, showcasing my ability to merge aesthetic design with engineering solutions. Throughout the development process, I conducted extensive research to select the most suitable materials and manufacturing techniques, ensuring that every component of the Custorim rim system not only meets but exceeds the required performance and aesthetic standards.

Additionally, I undertook a thorough exploration of all facets typical of a traditional rim company, including the creation and branding of the Custorim product line. This involved developing a comprehensive marketing strategy and pricing model to ensure market competitiveness and viability. A detailed product catalogue was also created to enhance consumer engagement and provide clear, accessible information about the product offerings.

The outcome is a manufacturable product, optimized for both performance and sustainability, and ready for real-world testing and future enhancements. This initiative not only exemplifies innovative approaches in traditional manufacturing sectors but also positions the Custorim system as a viable candidate for industry adoption and further academic exploration.

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2. Background Research
2.1 Evolution and Principles of Rim Design

The automotive industry's continuous quest of performance, safety, and aesthetic superiority can be seen in the history of rim design. Since the earliest days of the automobile, wheels have been an integral part of the vehicle's identity and operation. At first, steel was used to make simple, functional rims since steel was a widely accessible and strong material. Nevertheless, the weight of these early designs reduced the vehicle's performance and economy. These steel rims are still in use by some vans or other big vehicles.

Historical Context and Key Developments:

Rim design evolved alongside automotive technology. A big change was brought about by the alloy rims. These magnesium or aluminum rims provided a good mix of strength and lightweight, improving performance by lowering unsprung mass. This advancement highlighted an idea that is still essential to modern rim design: the search for materials that provide the best performance without sacrificing durability or safety.

However, the real revolution in rim design happened with the introduction of CNC machining and forging alloys production processes. Unmatched precision made possible by CNC machining made it possible to create intricate designs that were both better in terms of functionality and aesthetics. In contrast, the rims' material qualities were enhanced by forging, which made them lighter and stronger than their cast equivalents.

Principles Guiding Current Rim Design:

When dealing with the intricacies of contemporary rim design, a number of key concepts have been identified:

- Structural Integrity: Most importantly, rims must be strong enough to hold up car loads and handle the rough conditions of driving. This necessitates a thorough equilibrium between the qualities of the material and the design and should be tested by conducting FEA analysis on the rim digitally prior to manufacturing stage.

- Weight Optimization: Minimising the weight of rims, while maintaining their strength, directly impacts vehicle performance, fuel efficiency, and handling.

- Aesthetic Considerations: In the current market, rims serve as both a practical component and an aesthetic way of expressing users's style. Designers are responsible for developing rims that enhance the vehicle's overall visual attractiveness while also aligning with consumer preferences.

- Manufacturing Efficiency: Due to the progress in manufacturing technology, there is an increasing focus on improving the production of rims by eliminating waste and raising cost-effectiveness.

- Manufacturability: The ability to make the rim shape is a concept that is becoming more and more important. It is crucial that designs are created with a thorough comprehension of the production processes at hand, whether it be forging, casting, or flow forming. This comprehension guarantees that the design can be implemented within the limitations of the chosen production technology. Designers must collaborate closely with production teams to guarantee the feasibility of the envisioned design while maintaining high standards in terms of quality, performance, and aesthetics. The partnership is essential for balancing the trade-offs between the intricacy of design and the feasibility of production, eventually resulting in a unique and feasible product.

Conventional Cast Aluminium Alloy Rim Manufacturing Steps

Fig. 1. Conventional Cast Aluminium Design and Manufacturing Stages (Level3 - CMS - Placement Report)

Incorporation of Advanced Manufacturing Techniques:

The utilization of advanced manufacturing techniques is crucial for achieving the desired rim design, in addition to the foundational manufacturing method. CNC machining enables the meticulous fabrication of elaborate patterns and complex geometries, guaranteeing both visual attractiveness and practical refinement.

After the machining process, additional methods such as as tumbling are used to provide enhanced surface finishes, which improve both the visual appeal and durability of the rim.

Subsequently, powder coating is used to provide a long-lasting and resistant covering that protects against corrosion. This coating may be personalized with a diverse selection of colours.

2.2 Current Trends in Design and Manufacturing

The industry of rim production continues to lead the way in technical advancements in the automobile sector. In recent years, there have been notable developments in rim manufacturing that not only change the way the procedures are done but also tackle long-standing concerns regarding performance, aesthetics, and sustainability.

Technological Advancements in Rim Manufacturing:

An important advancement has been the extensive implementation of CNC (Computer Numerical Control) machining, which allows for the accurate creation of rims with detailed patterns and advanced shapes.

This technology has transformed the production of rims by enabling a previously unachievable level of design detail and structural strength, satisfying the performance and aesthetic requirements of modern day customers.

Tumbling machines have greatly enhanced the post-production process by improving surface finishes and efficiency, resulting in visually attractive and functionally superior end goods.

Moreover, the implementation of titanium powder 3D printing has expanded the limits of rim design, allowing for the production of structures and shapes that provide enhanced performance and distinctive aesthetics but this method is not widely use because of it’s manufacturing cost, time constrains and mass production limits.

Advancements in Materials and Improvements in Processes:

The progression of rim production has also been influenced by advancements in materials and improvements in manufacturing techniques. Heat treatment of certain alloys has become a crucial development, strengthening the tensile characteristics of rims, therefore improving their strength and longevity without adding extra weight.

This procedure enables the enhancement of mechanical qualities, guaranteeing that rims can withstand the strains of driving while improving vehicle performance.

Magnesium alloys have greatly transformed the process of choosing materials for rim production. These alloys have gained popularity due to their exceptional durability, low weight, and resistance to corrosion. They aid in decreasing unsprung mass, a crucial aspect for vehicle dynamics and fuel efficiency, while also providing enhanced durability and resilience to weather elements.

Alloy forging techniques have seen substantial advancements, resulting in the creation of rims that are both lighter and more durable than previous iterations. This method, together with progress in alloy composition, forms the basis for the creation of rims that significantly enhance vehicle efficiency and performance.

The Challenge of Cast Wheels:

However, the continued popularity of cast wheels in the market highlights an ongoing obstacle. The constraints associated with cast wheels, particularly regarding cost-effectiveness and the trade-off between weight and strength, remain a source of worry for both design engineers and automobile fans. Nevertheless, the industry's commitment to innovation and the use of cutting-edge manufacturing processes and materials has the potential to overcome these challenges, leading to the development of rims that surpass expectations in terms of performance, aesthetics, and sustainability.

Being able to manufacture high-strength, lightweight wheels using today's manufacturing technologies and combining them with creatively designed, cost-efficient, functional 3D-printed additional spokes by a CNC-machined attachment system demonstrates how enhanced today's technologies are!

2.3 Material Selection and Sustainability Considerations

Exploring and using advanced materials and processes in rim design is a crucial step towards innovation in automotive components manufacture. This transformation is clearly demonstrated by the potential use of cutting-edge alloys, such as Elektron 21 magnesium, and the innovative implementation of ABS plastic for manufacturing additional rim spokes using 3D printing technology.

These advancements provide improvements in both performance and sustainability, as well as a transformation in production efficiency.

Advancements in Alloy Technology: ***Elektron 21 ® - Magnesium***

One area of focus in materials innovation is the study of magnesium alloys, namely Elektron 21, which is known for its outstanding characteristics. Elektron 21 magnesium alloy has a higher strength-to-weight ratio compared to conventional materials like aluminium or steel. This characteristic is crucial for the automotive sector as it allows for the development of lighter wheel rims without compromising their strength or endurance. The utilisation of Elektron 21 for producing the base wheel is a pivotal aspect of this project, representing an exploration into unfamiliar area where this material has not been used before.

Elektron 21 stands out because to its exceptional corrosion resistance and high temperature resistance, making it a perfect option for high-performance rim production. These attributes not only guarantee the rims' long-lasting and sturdy nature in different weather circumstances, but also enhance the vehicle's safety, d ependability, and overall performance.

The adoption of Elektron 21 serves the purpose of enhancing vehicle performance by reducing unsprung mass, resulting in improved handling and acceleration. Additionally, it demonstrates a dedication to environmental responsibility. Elektron 21 aids in the creation of thinner rims using fewer materials, which supports a sustainability framework that minimises resource usage and corresponds with worldwide ecological objectives.

6061(T6) - Aluminium:

After investigating the usage of Elektron 21 magnesium for the high-performance base rim of Custorim, the project also explores the possibility of using 6061-T6 aluminium alloy as a more accessible option for making the base rim. This choice is motivated by the intention to create an alternative that, although somewhat heavier, offers a cost-effective option without considerably sacrificing the fundamental qualities of durability, usefulness, and aesthetic appeal. This variation is particularly suitable for everyday automobiles.

Achieving Equilibrium:

6061-T6 aluminium is well recognised for its diverse use in several sectors, thanks to its exceptional combination of strength, resistance to corrosion, and ability to be welded. By subjecting the alloy to heat treatment and ageing it to its T6 temper, its strength is greatly enhanced, making it a very suitable choice for the Custorim base rim intended for regular and frequent usage.

This alloy enables the production of rims that are durable and able to withstand regular use without damage, while also providing a lighter option compared to conventional steel rims.

The main drawback of the 6061-T6 aluminium alloy type is a moderate increase in weight compared to the Elektron 21 magnesium base rim. Nevertheless, the variation in weight is meticulously adjusted to guarantee that it does not have a negative impact on the performance of the vehicle in its intended everyday situation. The aluminium rim, although somewhat heavier, falls within a weight range that promotes fuel efficiency and handling. This allows for a balance between cost-effectiveness and performance.

Economical and Environmentally Friendly:

Selecting 6061-T6 aluminium as the material for the base rim is in line with the project's main objective of increasing the availability of sustainable and high-quality rim choices. The alloy's extensive utilisation and convenient processing lead to a reduced production cost, enabling the creation of a more economical final product.

Moreover, the recyclability of aluminium is advantageous for sustainability initiatives, since it guarantees that the rims may be recycled when they reach the end of their lifespan, therefore minimising their environmental footprint.

Integration with the Custorim System:

The 6061-T6 aluminium base rim, like its magnesium equivalent, can be utilized to smoothly connect with the customisable ABS plastic extra spokes. This guarantees that those who use their vehicles on a daily basis and do not want to spend much money on new set of rims can also take advantage of the cutting-edge capabilities of the Custorim system.

The addition of a 6061-T6 aluminium alloy variation to the Custorim collection represents a dedication to promoting diversity and inclusivity in rim design. Consumers are given the freedom to select a rim that aligns with their own requirements, preferences, and financial constraints, while still maintaining the high standards of quality, performance, and environmental consciousness that are integral to the project's purpose.

Integrating 3D Printed ABS Plastic in Rim Design:

Continuing the conversation about improvements in alloys, the incorporation of ABS plastic using 3D printing technology introduces another aspect of innovation in the production of rims.

More precisely, the utilisation of Fused Deposition Modelling (FDM) printers enables the effective and adaptable manufacturing of rim spokes using ABS plastic. This method allows for a wide range of design options, giving designers the ability to explore intricate shapes and customised arrangements that emphasise both appearance and practicality.

Sustainability in Rim Design - A Collaboration of Magnesium and ABS Plastic:

The integration of durable, lightweight magnesium wheels with cost-effective, eco-friendly recycled ABS plastic for potential supplementary spokes is a pioneering strategy in the advancement of sustainable vehicle manufacture.

This novel combination not only meets the industry's need for rims that are both high-performing and visually appealing, but also supports larger environmental goals by decreasing the ecological impact of production processes and the cars themselves.

2.4 Market Research and Industry Analysis

The automobile rim industry is currently at an important stage, influenced by changing customer preferences, technical progress, and an increasing focus on sustainability. This research examines the present condition of the market, emphasising significant patterns, customer inclinations, and the deficiencies that exist within the business. The section delves more on how Custorim intends to tackle these difficulties with its inventive rim system.

Market Analysis - Evolving Customer Needs and Technological Progress:

Consumers are increasingly searching for rims that provide both visual attractiveness and practical improvements. This encompasses requests for enhanced brake cooling, advancements in aerodynamics to optimise electric mileage in electric vehicles, and decreased drag coefficients in high-performance automobiles.

The market is transitioning towards products that not only improve the vehicle's appearance but also boost its overall efficiency. To fulfil these extensive requirements, lightweight alloys and advanced materials are being investigated.

The increasing popularity of electric vehicles (EVs) and the growing emphasis on environmentally friendly products have significantly boosted the demand for rims that meet these changing criteria.

Market Research:

This market research examines four key product categories in the vehicle wheel industry that are crucial for analysing the competitive landscape of Custorim's distinctive offering. These categories are Wheel Covers, Aluminium Aftermarket Wheels, Magnesium Aftermarket Wheels, and Customisable Aftermarket Wheels. Every category represents a unique sector with distinct customer preferences, performance characteristics, and market dynamics. Comprehending these classifications will assist in defining Custorim's stance and recognising possibilities for uniqueness and differentiation.

Wheel Covers

Wheel covers, like those from brands such as Sparco, are marketed as affordable solutions for enhancing the aesthetics of older rims, typically available for around £60 on major retail platforms like Amazon UK.

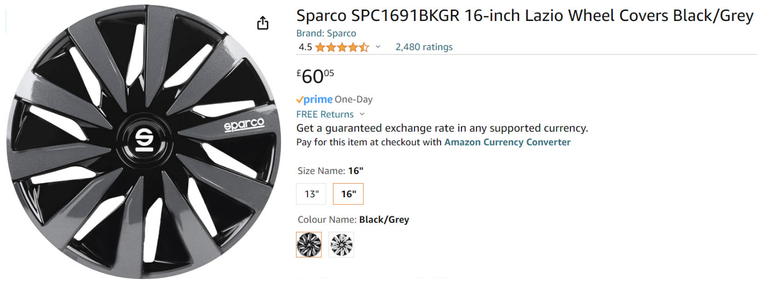


Fig. 2. Sparco 16 inch wheel cover Lazio (Amazon.uk)

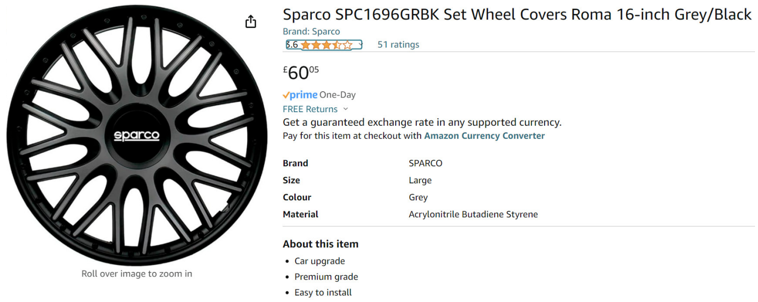


Fig. 3. Sparco 16 inch wheel cover Roma (Amazon.uk)

However, these products often face limitations in design and quality:

- Design Uniformity: Most wheel covers feature a standardized design that may not suit the varied aesthetic preferences of different vehicles, resulting in a look that can appear mismatched or incomplete.

- Quality Concerns: The affordability of these covers is frequently equated with poor quality, which can deter potential buyers who value durability and design integrity.

Aluminium Aftermarket Rims

Aluminum aftermarket wheels are highly sought after for their blend of aesthetic appeal and performance benefits.

These wheels offer extensive customization options, with a variety of styles, finishes, and sizes available to suit individual preferences, thereby significantly enhancing the visual appeal of any vehicle.

They are not only lighter and more aerodynamic than stock rims but also designed to accommodate larger brake systems, improving handling, acceleration, and overall driving performance.

Fig. 4. Romac Radium Gloss Black 19inch (www.wheelbasealloys.com, n.d.)

Fig. 5. CVR1 Brushed Bronze (www.wheelbasealloys.com, n.d.)

Pricing Variability:

The cost of aluminum aftermarket wheels varies widely, ranging from approximately ~£500 up to ~£5.000.

The manufacturing process for cast aluminum wheels often imposes constraints on the spoke design. Typically, these wheels feature bolder and thicker spokes, which can limit the ability to achieve sleek, lightweight designs.

Fig. 6. OZ Rally Racing Graphite 19inch (www.wheelbasealloys.com, n.d.)

Forged aluminum wheels are typically lighter than cast wheels. The strength of the material allows for the construction of slimmer, more elegant spokes without compromising durability. This reduction in weight is crucial for performance vehicles, as it leads to better handling, quicker acceleration, and improved fuel efficiency.

Magnesium Aftermarket Rims

Magnesium aftermarket wheels represent the apex of wheel technology, highly prized for their ultralight properties and superior performance characteristics. Predominantly used in racing and high-performance sectors, these wheels offer unparalleled advantages.

Exclusive Market: Magnesium wheels are predominantly found in specialised markets, namely among race enthusiasts and high-performance car owners that want the utmost level of performance.

Fig. 7. IPE MFR-02 Magnesium Aftermarket Wheels (String Theory Garage, n.d.)

Fig. 8. BBS RE-MTSP (BBS RE-MTSP - 19, 2017)

The elevated price of magnesium as a material, coupled with specialised production methods, results in these wheels being pricier than aluminium counterparts, which restricts their broad use.

There is an increasing demand for magnesium wheels due to their performance advantages, particularly in the sports and luxury vehicle industries, even though they are more expensive.

Customizable Aftermarket Rims

The Rotiform Aerodisc system is a very unique product in the customisable rim industry. This solution enables customers to customise the appearance of their rims by affixing circular stickers, which can modify the look of their wheels. The rim's design is optimised to reduce drag coefficient, making it a crucial component.

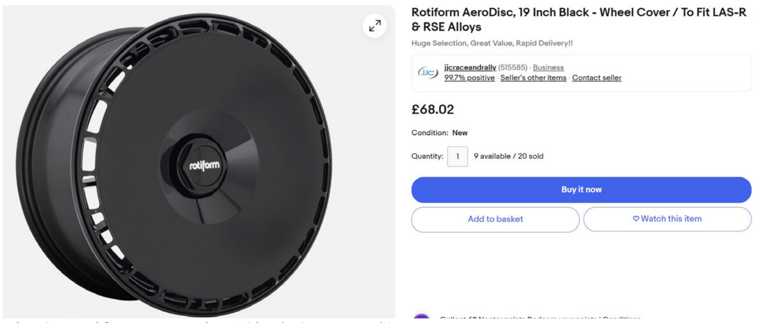


Fig. 9. Rotiform AeroDisc 19inch (eBay, n.d.)

While Aerodiscs offer customization, the stickers used are flat and 2D, lacking photorealistic qualities. This can result in a less authentic, manufactured look that might not appeal to all users, particularly those seeking a more integrated and realistic enhancement that maintains the wheel's natural aesthetics.


Fig. 10. Rotiform AeroDisc Sticker Variations (artstation, n.d.)


Fig. 11. Rotiform AeroDisc in use (Pinterest, n.d.)

Industry Implications: Closing the Gap Between Functionality and Aesthetics:

Rim designers and manufacturers face a daunting task in the current market: developing a product that is both sustainable, inexpensive, visually appealing, and technologically sophisticated. The industry encounters a significant gap, since current solutions are unable to meet these requirements within a single set of rims.

Consumers feel obligated to buy multiple aftermarket wheels to fulfil various requirements. Some prioritise unique designs but sacrifice performance, while others prioritise durability and lightness but lack aesthetic appeal.

2.5 Addressing Market Gaps with Custorim: A Interchangeable Rim System

Custorim aims to transform the rim market by combining high-performance characteristics with visually appealing aesthetics using a magnesium or aluminium foundation rim and combining it with light-weight, aesthetic and functional additional spokes.

This method seeks to address the many requirements of sustainability, affordability, improved functionality, and innovative design within a unified rim system.

Sustainable Innovation:

The choice of using Elektron 21 magnesium alloy for the base wheel takes advantage of its lightweight, resilient, and high-performance properties, which are well-suited for improving vehicle aerodynamics and facilitating brake cooling.

Furthermore, the utilisation of 3D printing technology to incorporate ABS plastic additional spokes into the rim design represents a significant advancement in terms of customisation and sustainability while being inexpensive.

Personalisation and Adaptability:

Custorim offers users the option to customise their rims by providing interchangeable spoke designs.
This allows them to meet unique requirements, whether it is for aesthetic preferences or practical necessities.

Conclusion

A Interchangble Rim System Combining Performance and Aesthetics

Custorim's methodology not only caters to the current requirements of the automobile industry but also sets the stage for a future when rim production represents a seamless combination of novelty, efficiency, and ecological accountability.

This research showcases the feasibility of developing a rim system that is environmentally friendly, affordable, visually varied, and technologically advanced, therefore setting a new standard in the car rim industry.

2.6 Addressing Engineering and Manufacturing Challenges

This project focuses on overcoming several intricate technical and manufacturing obstacles in the creation of a cutting-edge rim system. The goal is to combine the advantages of forged magnesium or possibly aluminium wheels with the ability to customise and use environmentally friendly ABS plastic for extra spokes.

Design Engineering Challenges and Solutions:

An important obstacle is the production of a rim that combines a lightweight yet strong magnesium alloy base with embedding a user-friendly attachment for connecting ABS plastic additional spokes.

This requires:

- Developing a thin, lightweight, and durable Forged Magnesium Wheel

The rim must feature embedded attachment cavities without compromising its structural integrity. Advanced production techniques like as CNC machining and forging are used, combined with T6 heat treatment, to improve the material qualities.

- Unsprung Mass Considerations:

The use of ABS plastic spokes gives rise to issues regarding the augmentation of the unsprung mass. Detailed weight calculations ensure these components remain lightweight and between toleranced levels to preserve vehicle dynamics.

The design guarantees uniformity and balance by carefully positioning extra spokes to preserve the centre of gravity. Custorim recommends to consistently adding spokes to all rims throughout assembly to prevent any weight imbalances.

- Balance and Center of Mass

The design guarantees uniformity and balance by strategically positioning additional spokes to maintain the centre of mass. Custorim recommends adding the same spokes design to all 4 rims during assembly to prevent any weight imbalances.

- Environmental Durability of ABS Spokes

Addressing the possibility for UV-induced damage to ABS plastic, a UV-resistant clear coat is applied to preserve color and integrity of the Additional Spokes.

- Diverse Range of Material Choices

Custorim attempts to address the substantial difficulty of providing the same base rim design in both magnesium alloy and aluminium alloy. This entails the need to apply heat treatment and forging to the aluminium alloy base rim in order to improve its tensile qualities with less material. The aluminium alloy base rim is a more affordable substitute for the magnesium base rim.

Customers have the freedom to select materials depending on their budget and performance choices, without sacrificing style or utility.

2.7 Evidence of Research

The design direction of this project is supported by a combination of primary and secondary research;

Primary research includes the utilisation of Finite Element Analysis (FEA) to assess the strength of the structure, conducting material tests on magnesium and aluminium alloys. The research includes essential weight estimates for ABS extra spokes and magnesium base rims to ensure that the design fulfils performance and sustainability objectives. I have also protyped the final designs using 3D ABS and Resin printers for testing the assembly of additional spokes on to the base rim.

Secondary research involves doing market analysis to get insights into current trends and customer preferences, analysing competitors to establish benchmarks, and reviewing technical literature to understand material qualities and production procedures.

While designing and testing these rims, I employed industry-standard design and digital testing methods, conducting the most appropriate tests. I developed these approaches by studying academic articles and other thesis writings, as well as drawing on knowledge from my past internship experience. This ensured that I was on the right track throughout the project.

To obtain a thorough understanding of these studies, which includes precise calculations, additional graphs, and thorough descriptions of how technical issues were tackled, please consult Section 3 of the report, specifically titled “Development Process.”

3. DEVELOPMENT PROCESS

Custorim User Archetypes

“Innovation Pioneer”: (***FUTURIST*** **- series)**

Characteristics: These users are constantly searching for the newest and best developments in vehicle and wheel design and technology. They are proud to be among the first to test and acquire the latest innovations. They value uniqueness and are willing to invest in high-quality, cutting-edge products and designs.

Preferences: These users are drawn to the Futurist Series, which boasts a futuristic look on the design, with features like curve, asymmetric and 3D design. This appeals to their desire for products that stand out and offer creative, unseen, futuristic looks.

Lifestyle: These are users who experienced with technology can keep up with the newest developments in automobile design and technology. They often be involved in automotive clubs or online communities where they can showcase their unique vehicle modifications.

“Quiet Classic Adherent”: (***Classic*** **- series)**

Characteristics: These users prefer not to draw excessive attention with their rim designs. Prefers subtlety and timeless designs, steering clear of new trends. They often view new rim design trends as transient moments in the extensive timeline of vehicle design. They appreciate reliability, strength, and designs that share classic aesthetics, embodying a sense of heritage and sophistication.

Preferences: Drawn to Custorim’s classic and familiar looking spoke designs that don’t seek much attention but complement the vehicle’s overall elegance which is Classic Series. They care about product durability, and aesthetic over flashiness, with a keen eye for craftsmanship.

Lifestyle: They have the same taste on their clothing, accessories, and car model choice. They are likely participants in vintage car gatherings and enjoy sharing their passion within cultured, like-minded communities.

“Performance Seeker”: (***Performance*** **- series)**

Characteristics: Focused on optimizing their vehicle's performance, The Performance Seeker user archetype looks for products that offer tangible benefits in efficiency, performance, and overall vehicle dynamics. They are knowledgeable about the technical aspects of automotive products and make decisions based on specifications and performance outcomes.

Preferences: The Performance series, with spokes designed to decrease drag coefficient and enhance brake cooling inspired by jet engine designs, is perfectly aligned with Performance Seeker's goals. This user appreciates the thought and engineering behind creating spokes that not only look good but also provide performance advantages.

Lifestyle: This archetype is likely to be very knowledge about their vehicle’s dynamics, fuel or electric usage and they might be engaged in online forums and communities that discuss vehicle modification and performance enhancement. Also, they tend to have an attraction towards electrical vehicles.

3.2 Custorim Base Rim Design Iterative Process

Conceptualization and Design Direction

CB1

Introduction:

The Custorim base rim aims to develop an innovative rim design that not only enhances the aesthetics of a vehicle but also introduces a new additional spoke system, extreme durability, and great weight to size ratio.

System Inspiration:

When designing the base rim of Custorim, I was significantly influenced by the HRE3D+ rim from HRE, a company that had caught my attention during prior research. This model inspired me to think about rim design in a more three-dimensional and intricate manner than I had before, pushing the boundaries of traditional rim aesthetics and functionality.

Fig. 12. HRE3D+, 3D-Printed Titanium Wheel (Hrewheels.com, 2019)

Design Inspiration:

In designing the Custorim CB1 rim, it was crucial to ensure that the spoke designs were minimalistic. This not only provided sufficient space for the additional spoke designs but was also important from a material usage perspective. Thus, I drew inspiration from various rim designs featuring slender spokes. The design that particularly captured my attention was that of the Ferrari Roma rims, which stood out due to their simplicity and elegance.

Fig. 13. Ferrari Roma OEM Wheels (Modulare, n.d.)

Fig. 14. Ferrari Roma OEM Wheels (360WHEELS, n.d.)

Base Rim Concept Initial Objectives:

- Develop a system that enables users to personalize their car rims, allowing for quick and easy customization.
- Ensure that the car rims maintain their structural integrity, safety, and performance standards and capable of resisting high forces when cornering.
- Create a user-oriented product journey.
- Ensure that the rim is not only lightweight but also features ample space for the additional spoke designs to stand out prominently.

Technical Considerations:

Material Selection

The material for the base rim is designed to be manufactured in both magnesium alloy and aluminum alloy to accommodate various user preferences while maintaining identical dimensions and sizes. The selection of specific alloy materials and final measurements for these designs will be determined after conducting Finite Element Analysis (FEA) testing and analyzing the results to ensure optimal performance and durability.

Structural Integrity

It is crucial to ensure that the blank spaces between the main spokes are equally aligned with the center to prevent any weight imbalances and avoid resonance. This alignment is essential for maintaining the stability and performance of the rim

Compatibility

The design should be adaptable for various vehicle sizes, accommodating rim diameters up to 21 inches. This versatility ensures that the rim can be tailored not only to meet the performance requirements of different vehicles but also to align with individual aesthetic preferences.

Different users often choose rim sizes based on a combination of functional needs and the visual impact they desire on their vehicles, making it essential that the design supports a wide range of vehicle designs.

Fig. 15. Custorim CB1 Colour and Material Variations

Final Achieved Features:

- Attachment system for Custorim Additional Spokes.
- Thin, yet sturdy main spokes.
- Measurements match OEM rim standards.
- Positive offset.
- A design that is appealing even without the assembly of additional spokes.
- A design capable of withstanding and passing FEA testing with forces up to 500 kg acting on the main spokes.
- Can be manufactured in both Electron 21® magnesium alloy and 6061-T6 aluminum alloy.

3.3 Stages of Development

Design Engineering Solutions

1- Concept Development and Sketching

Initially, the development of my first concepts began during Term 1. These preliminary designs established the foundation for the main rim design. As the project progressed, I incorporated significant modifications based on valuable feedback from my tutors and expanded my explorations through additional sketches. This iterative process enabled me to integrate practical insights and expert suggestions effectively, progressively refining the design to better align with the project's objectives and to address both performance and technical

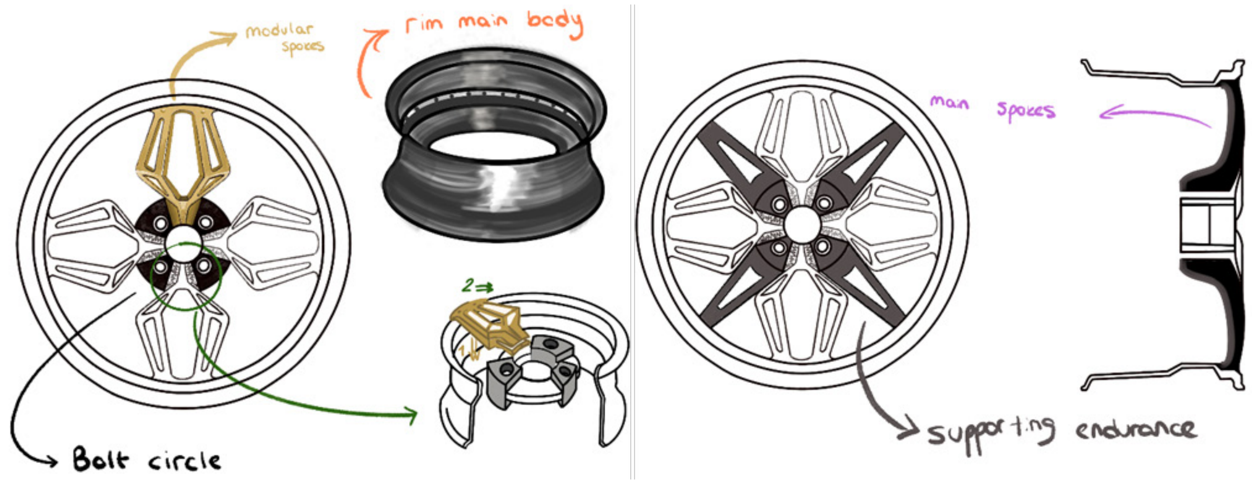


Fig. 16. Custorim System, Term 1, Concept Sketches

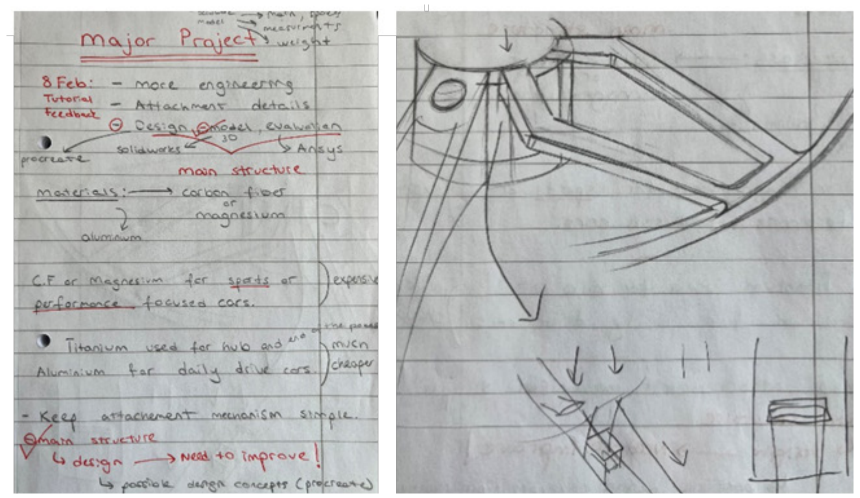


Fig. 17. Project Notebook Notes and Custorim Attachment System Development Sketches

I have generated and examined many iterations of base rim spoke designs. I have utilised all the remaining design sketches of these spokes to my benefit in the subsequent stages of additional spoke designs.

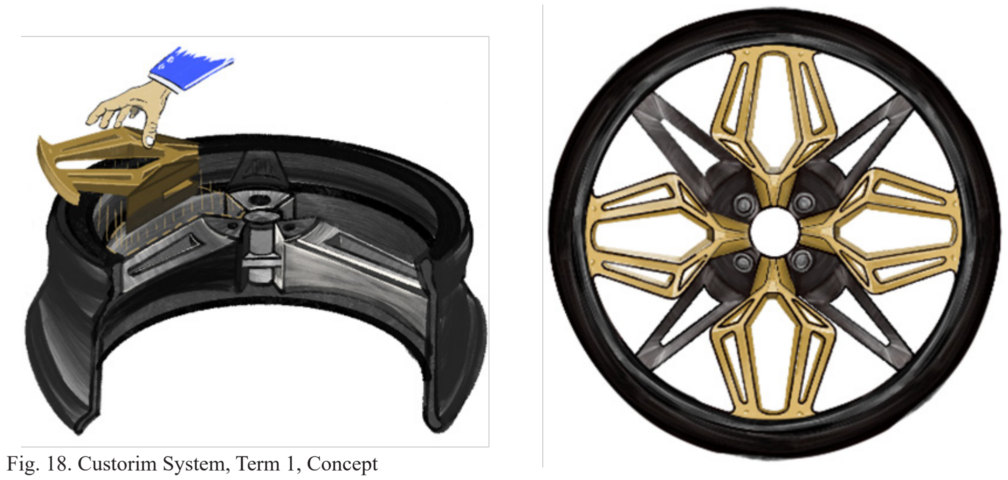


Fig. 18. Custorim System, Term 1, Concept

Here are some sketches from my exploration of spoke designs, highlighting the ones I've chosen for further development.

Base Spoke Sketches:

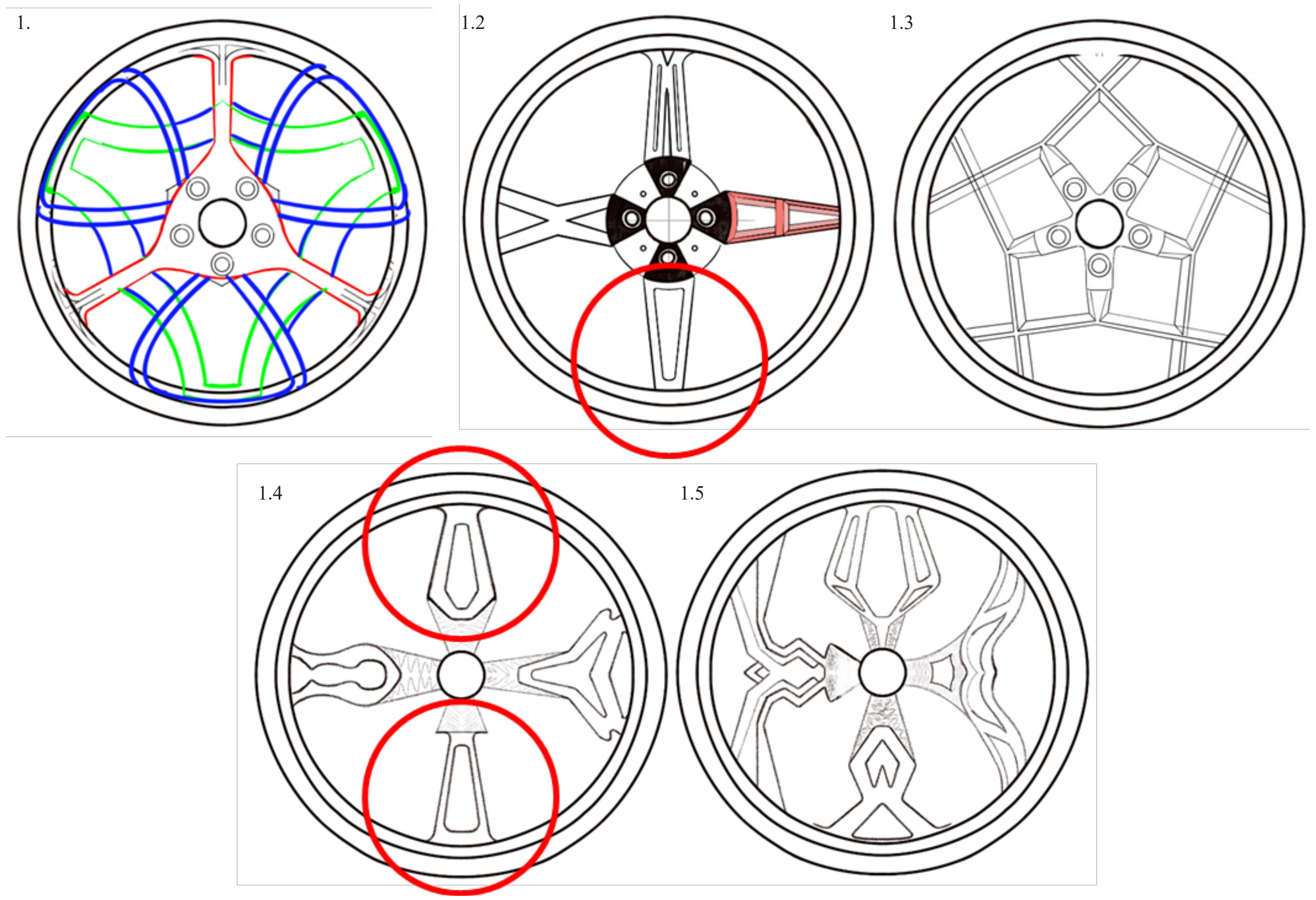


Fig. 19. Base Rim Main Spoke Design Ideation and Sketches

2- Foam Model Exploration of Attachment Geometries

After sketching various shapes for attaching the additional spokes to the main rim, I decided to test some of these geometries with foam models to ensure precise attachment.

Following extensive testing with different shapes, I selected the final attachment geometry for the base attachment.

Although digital modeling provides the advantage of pre-testing these interactions, physically testing them using materials like cardboard or foam is always beneficial to confirm their effectiveness

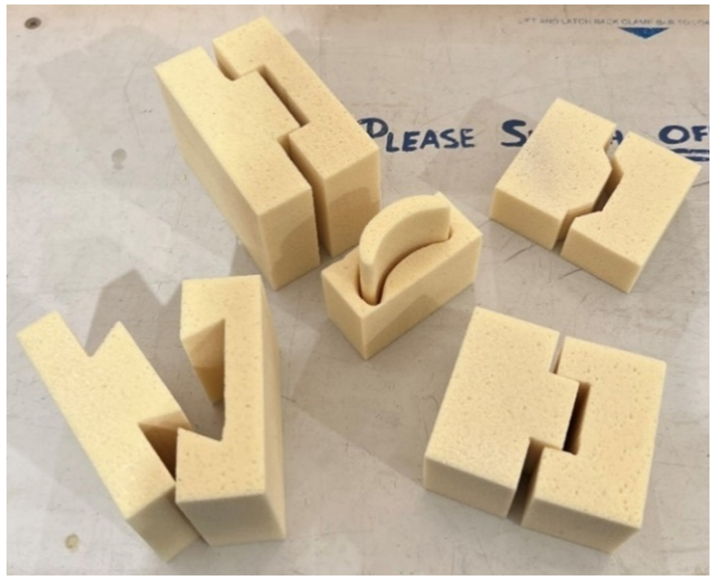


Fig. 20. Custorim Attachment Mechanism Foam Model Explorations

3- Initial Concept Model SolidWorks Digital Model

CAD

Custorim Base 1:

After further developing the sketches and ensuring the technical considerations and measurements were accurate, I created my initial digital model in SolidWorks.

This rim was the initial model; therefore, it lacked fillets, chamfers, and other additional features.

I initially focused on technical considerations and measurements, such as positive offset, rim, centre bore, and bolt diameter.

I did not pay much attention to the barrel wall thickness, length, and the surface where the rim and tire make contact at this stage of design process.

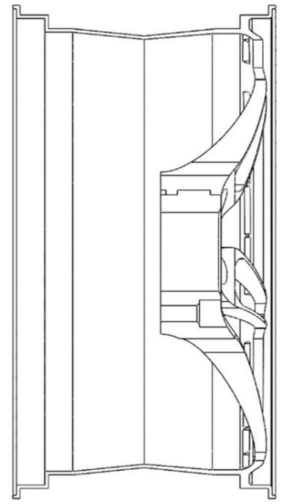


Fig. 21. Initial Base Rim Cross Section

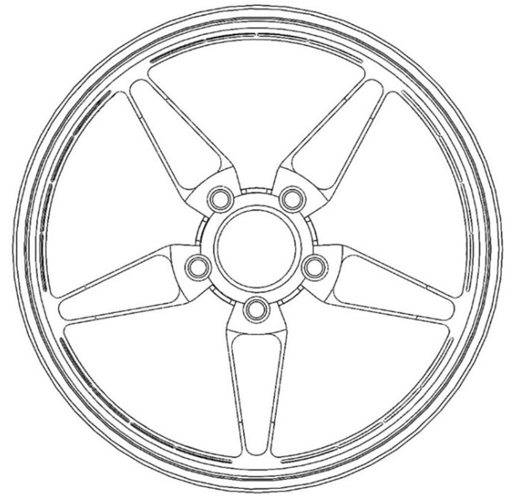


Fig. 22. Initial Base Rim Front View

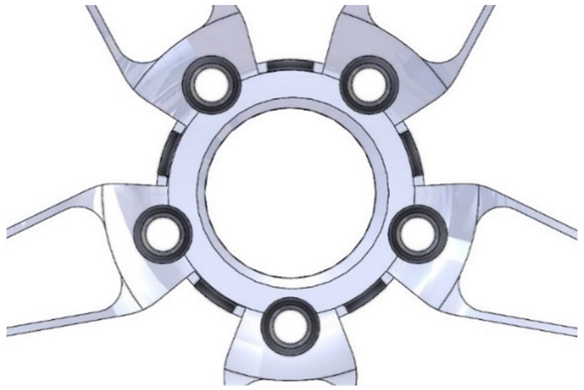


Fig. 23. Inital Model Centre Bore

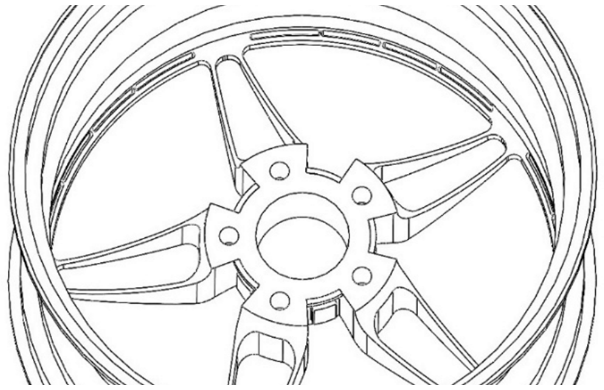


Fig. 24. Initial Base Rim Back View

4- Development of Digital Model

In this phase of development, I refined my model through several critical modifications to enhance its functionality and durability. Initially, I incorporated a support piece at the back of the rim. This addition was strategically placed to bolster the integrity and durability of the rim, supporting the main spokes from behind. Importantly, this enhancement did not alter the outer face of the rim that remains visible to the user, thus maintaining the aesthetic appeal.

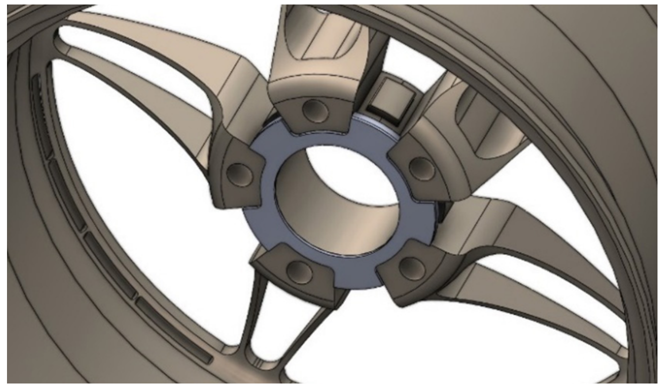


Fig. 25. Revised Base Rim Back View

Furthermore, I addressed potential stress points by smoothing sharp edges where necessary. This was accomplished by adding fillets, particularly at the back of the main spokes and around the outer shell of the rim, to improve handling safety and reduce the likelihood of stress concentrations, which can lead to material fatigue or failure.

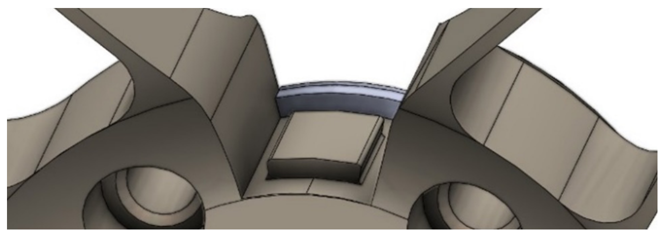


Fig. 26. Initial Base Rim Back View

At this stage, I also finalized the components of the base rim related to the attachment system.

The cavities located along the face of the rim are specifically designed for attaching the additional spokes and ensuring their stability.

This attachment system is simple yet effective, focused on ease of use to enhance the user journey and designed for self-assembly, allowing users to easily customize their wheels to their liking.

Fig. 27. Attachment Cavities Back View

Fig. 28. Attachment Front View

In the process of determining the optimal wall thickness, a range of variations was evaluated.

After identifying two different wall thicknesses, Finite Element Analysis (FEA) was employed to assess their performance. Ultimately, the choice was made by determining which model best showed a balance between durability and weight, maximizing the design's structural efficiency.

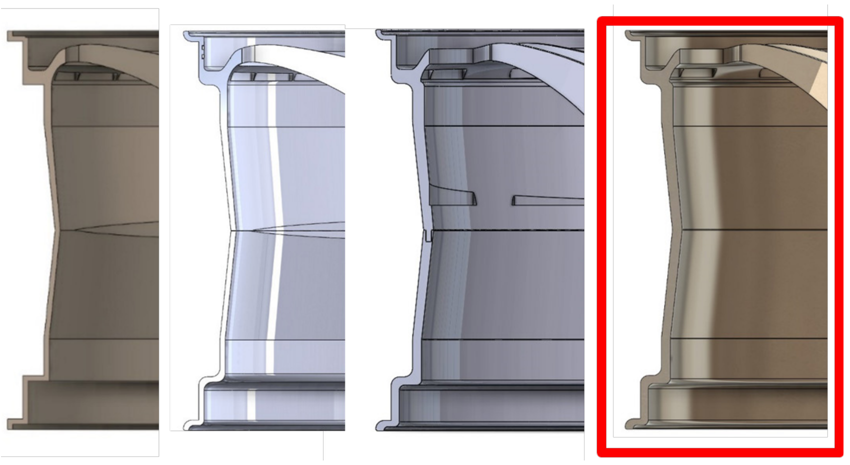


Fig. 29. Base Rim Wall Thickness Development and Final Wall Thickness

5- Final Digital Model of CB1 – Custorim Base Rim

Lastly, I corrected the errors I observed in my model and created the final digital model using the selected wall thickness.

All the key measurements and technical details can be further read in the "Base Rim Measurements, Safety, and FEA Testing" sections.

Fig. 30. CB1 Main Spoke

Fig. 31. CB1 Final Model made out of Magnesium

6- FEA Testing / Feasibility Analysis trough Solidworks Studies

FEA

At this stage, I conducted extensive Finite Element Analysis (FEA) testing on both the final rim model and a second model, which features a thinner wall thickness but shares identical measurements with the final rim model in all other respects.

I tested both magnesium alloy and aluminium alloy materials to ensure the rim could be manufactured using either material.

After reviewing the results of these tests, I decided to continue my project with the rim model that has a thicker wall thickness, as it proved to be better in terms of both durability and safety. This thicker rim model successfully withstood forces up to 5000N without showing any signs of breaking or damage, which was precisely the outcome I was expecting.

The methodology, reasoning, and intricate details of the Finite Element Analysis (FEA) process, accompanied by the discussion of its outcomes, are comprehensively detailed in Section 3.4 and 4. of the report.

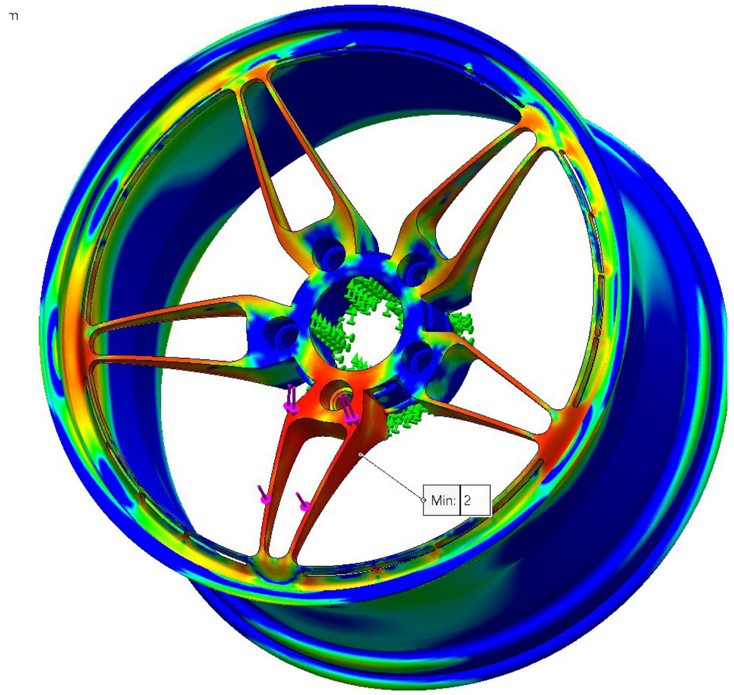


Fig. 32. CB1 Final Model FoS Test - Elektron 21 Results Image

7- Creating STL files for 3D printing

Prototyping

After completing all the previous stages, I selected the spoke designs I wanted to print and prepare for my Final Presentation Package. I arranged them in SolidWorks to visualize the final presentation before printing. Satisfied with the arrangement and the parts chosen for the presentation, I exported them as STL files and sent them to the dedicated staff at the 3D printing studio. Unfortunately, due to unforseen issues on the largest printer, the F770, was out of service and could not be repaired.

This situation forced me to adjust my arrangement and parts to fit the capabilities of smaller 3D printers, ensuring I could still produce suitable final physical prototypes.

Fig. 33. Initial Models for 3d Printing

8- Physical Prototyping

In this final stage, I regularly collected the parts that were ready from the 3D print studio every other day and transported them to the workshop for further processing.

Initially, I cleaned the 3D printed parts using water and tools to remove any residual printing material.

Subsequently, I embarked on the meticulous and labor-intensive task of sanding the parts, using sandpaper up to a 1500 grit to achieve the desired smoothness and finish. Recognizing the precision required for sanding, I approached the task with patience and attentiveness.

After achieving a satisfactory surface quality, I prepared the models for painting by first applying a primer, sanding it to the desired finish, and then applying the final paint and protection coat.
The coloring was done using purchased aerosol paint and existing spray paints in the workshop.

The parts processed in this stage included four additional spokes and a full rim scaled to 0.5.

Due to technical issues with the F770 3D printer's head piece, I adjusted the models to accommodate smaller scales. To showcase the assembly of the true-to-size additional spoke designs on the base rim, I sliced the full, true-to-size rim into five sections, removing unnecessary portions from the back of the rim barrel to the centerline.

This segmentation was essential to demonstrate the integration of components in a practical scenario.

Throughout this process, I ensured that all parts fit perfectly together without damaging the applied paint, confirming the functional viability and aesthetic appeal of my designs.

This phase of prototyping was crucial in validating that the designs not only worked as intended but also met the visual standards set for the Custorim project.

Fig. 34. Initial printed parts

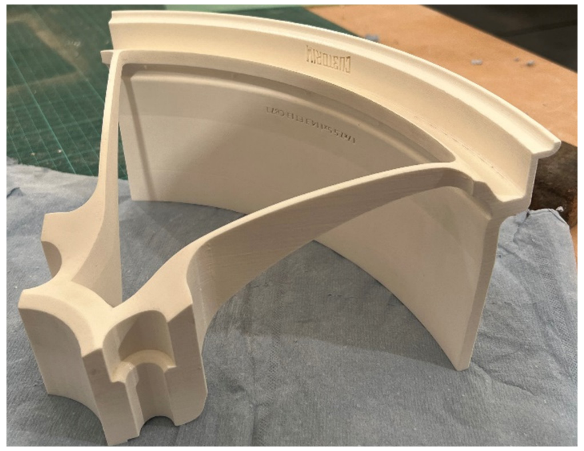


Fig. 35. CB1 - 1/5 Slice - True Scale

Fig. 36. Sanding of Base Rim

Fig. 37. Painted CB1 Base Rim

Fig. 38. CSF1 assembled on 1/5 Base Rim

Fig. 39. Additional Spokes Painted

3.4 CB1 - Final Base Rim Key Measurments and Analysis

Rim Diameter:

I selected a 17-inch diameter for my base rim model, a commonly used size for car rims. This choice allows me to demonstrate my designs in the context of everyday vehicle rims.

It is possible to change the wheel diameter by making minor adjustments to the design dimensions, as with any wheel.

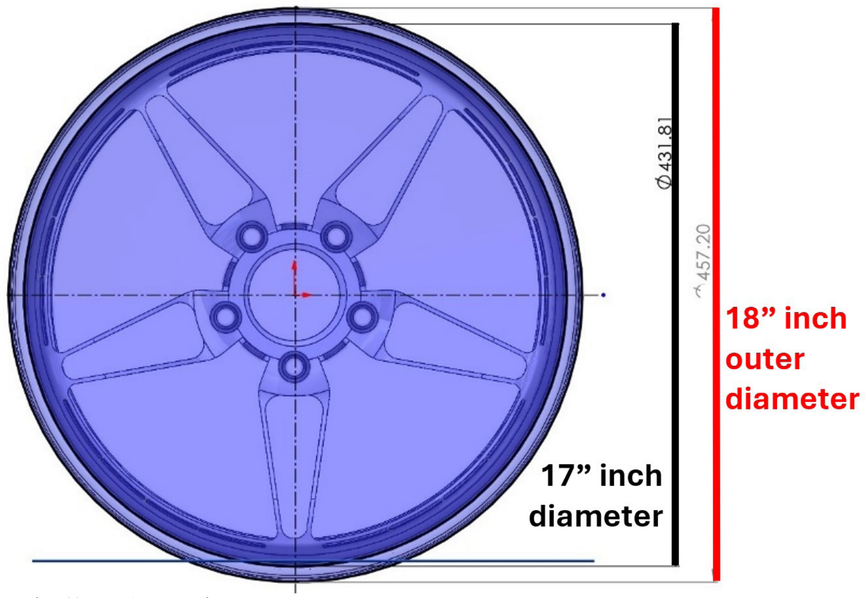


Fig. 40. CB1 Base Rim Measurments

Rim Width:

202.4 mm / 7.95” inches (according to recommended width to diameter ratio of researchs).

Fig. 41. CB1 Base Rim Width

Wheel Offset:

I opted for a **positive wheel offset** in the design of CB1, because this configuration offers enhanced compatibility with vehicles that are equipped with larger brake callipers. When there is a positive wheel offset, the mounting surface of the wheel is positioned closer to the face and more towards the outside of the wheel. This configuration helps the vehicle have a broader stance, which enhances handling and stability, in addition to provide the required clearance for larger brake callipers, which are frequently seen in performance.

Maintaining the integrity of the braking system and guaranteeing safe driving conditions depend heavily on minimizing the danger of friction or interference by making sure there is enough space between the wheel and the brake components.

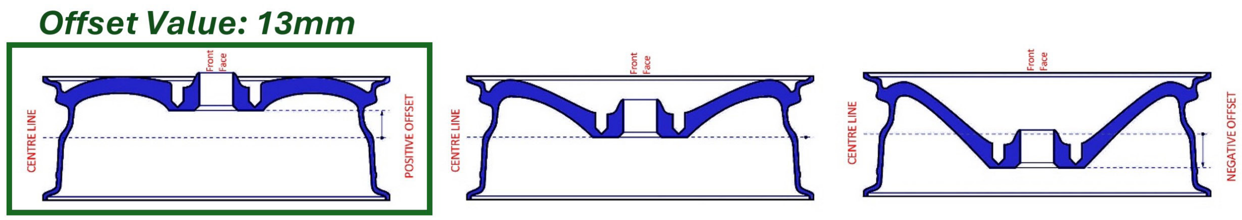


Fig. 42. Positive, neutral and negative offsets

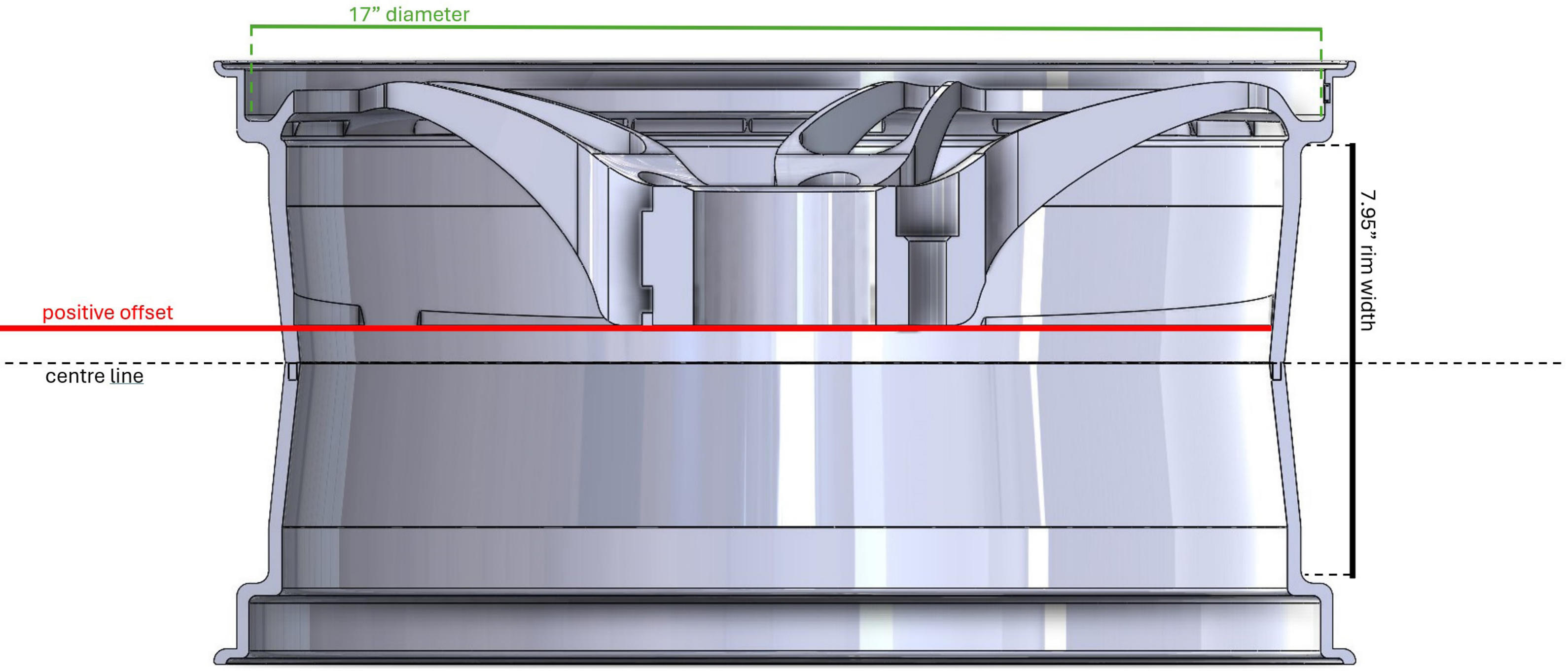


Fig. 43. CB1 Cross Section View and Measurments

Bolt Pattern / Pitch Circle Diameter (PCD):

One of the key specifications of this model is its bolt pattern, which consists of 5 holes for my project. This setup is critical since it dictates how the rim will fit and fasten to the car’s hub, affecting the installation procedure as well as the alignment of the wheels.

Custorim base model’s Pitch Circle Diameter (PCD) is precisely calibrated at 114.3mm.
“Pitch Circle Diameter (PCD) is the diameter of that circle which passes through the centre of all the bolts hole or wheel bolts or wheel rim holes or stud.”1. (KONIG, 2010)

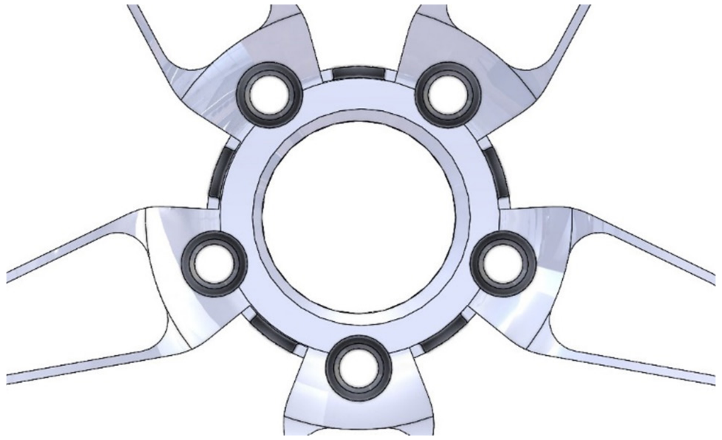


Fig. 44. CB1 Inner Hole

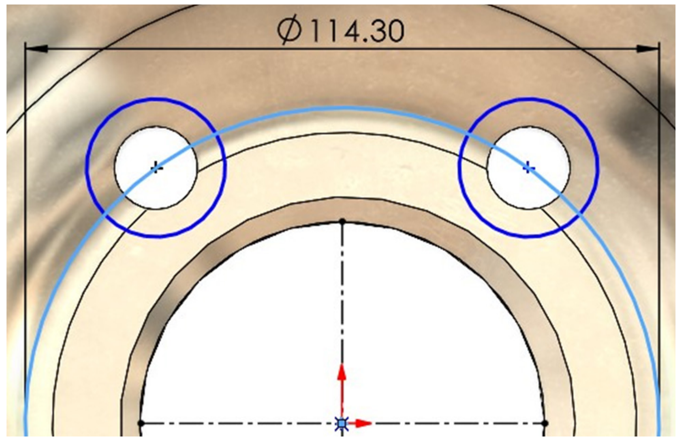


Fig. 45. CB1 Cross Section View and Measurments

Wall Thickness:

Figure ‘a’ presents a cross-section of the Custorim base rim with thin walls, measuring 3.1 mm for the barrel wall, whereas figure ‘b’ shows a variant with wall measuring 5.4 mm thick. Testing was done on two different wall thicknesses to find the best combination of durability and weight.

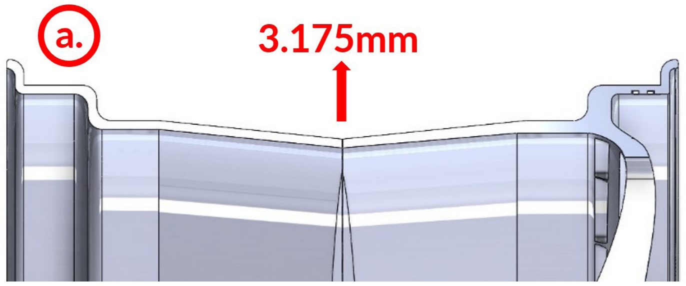


Fig. 46. Thin Barrel Wall CB1 model

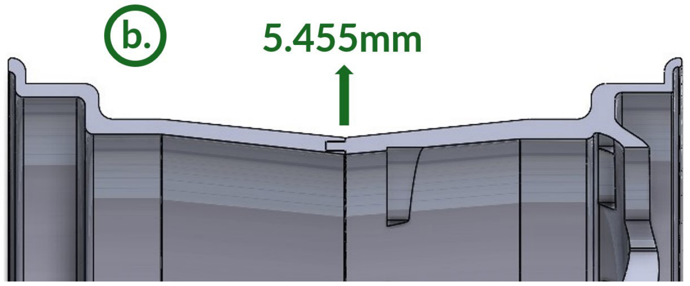


Fig. 47. Thick Barrel Wall CB1 model

Key Measurements of The Main Spokes:

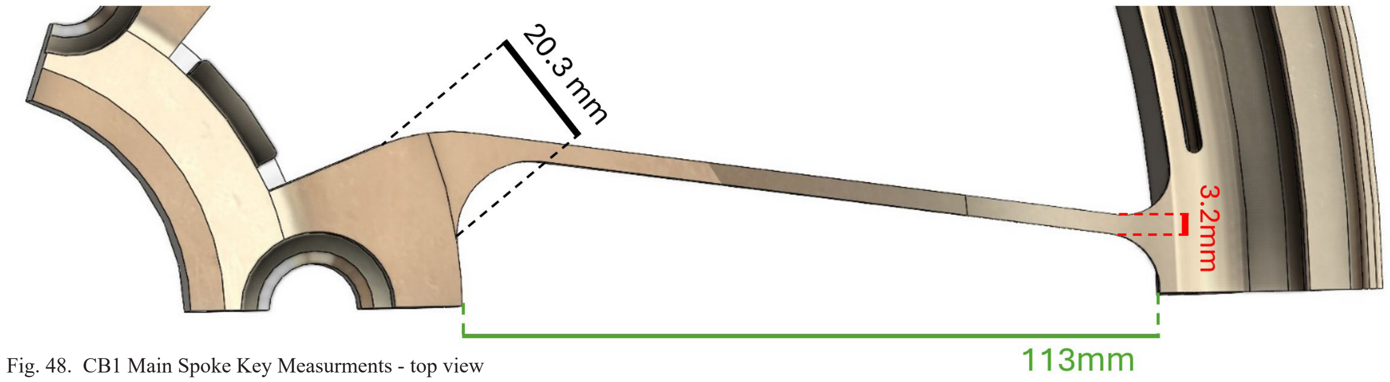


Fig. 48. CB1 Main Spoke Key Measurments - top view

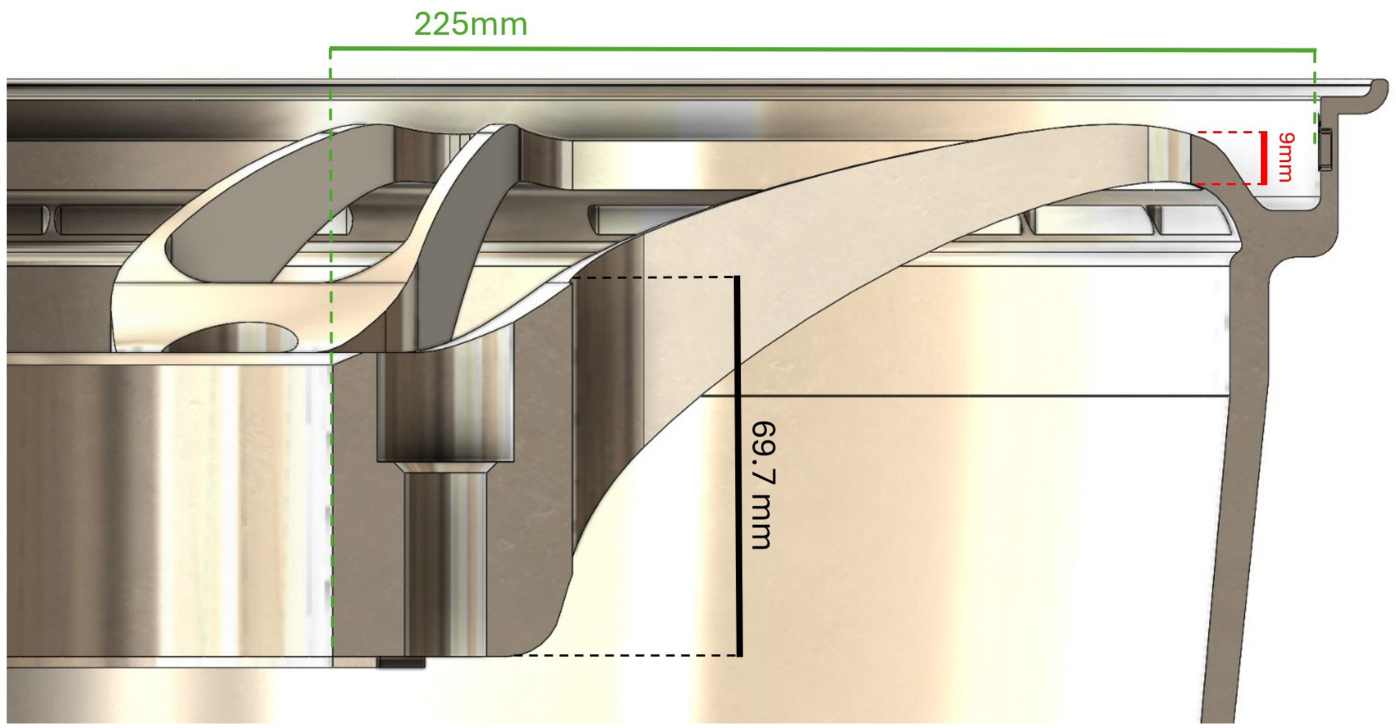


Fig. 49. Cross Section of CB1, main spoke measurments - side view

Centre Bore Diameter:

The centre bore of CB1 base rim has a diameter of **73 mm.**

Rim Weight Without Additional Spokes Assembly: (Magnesium alloy)

(a)Thin Wall Rim Mass = 3629 grams
(b) Thick Wall Rim Mass = 4771.9 grams

Weight of a standard 18-inch magnesium rim;
6.2 kg

Fig. 50. 18-inch magnesium wheels by MB Design (www.tunershop.shop, n.d.)

Weight of Custorim’s 17-inch rim;
4.7 kg

Fig. 51. CB1 Base Rim final model, centre cap assembled

Additional Customizable Custorim Spokes

Material Selection:

[ABS] Acrylonitrile Butadiene Styrene Plastic

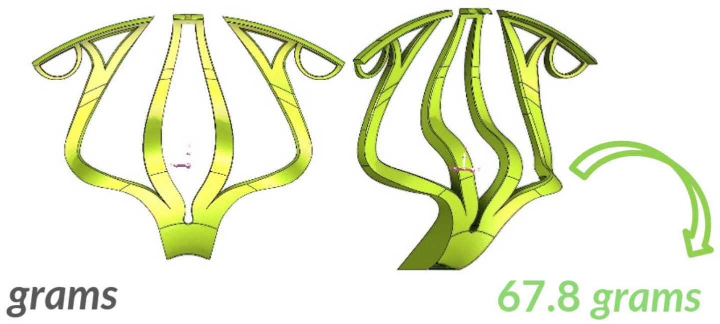
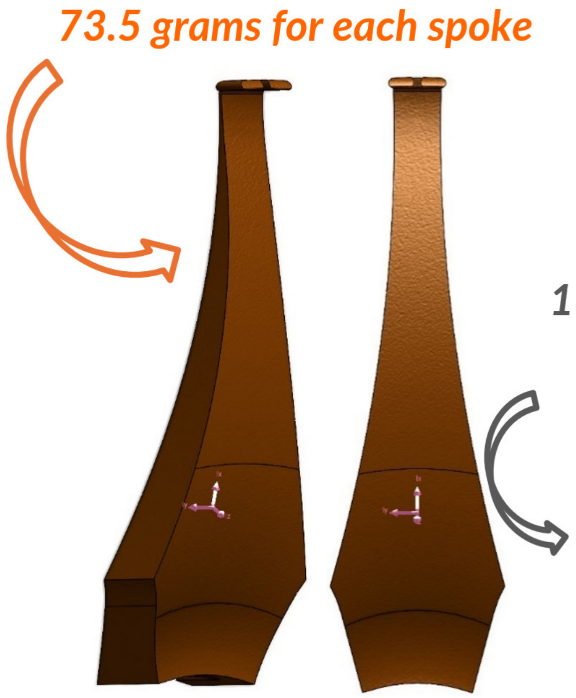


Fig. 52. CSF Series spoke



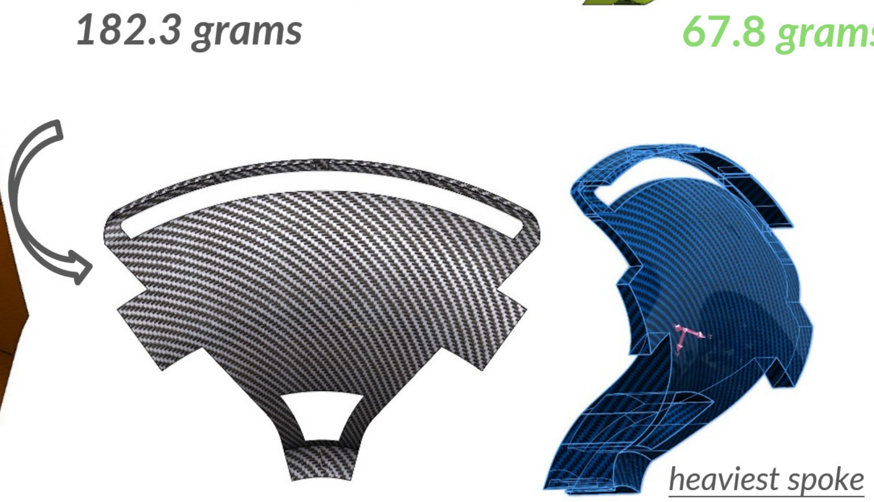
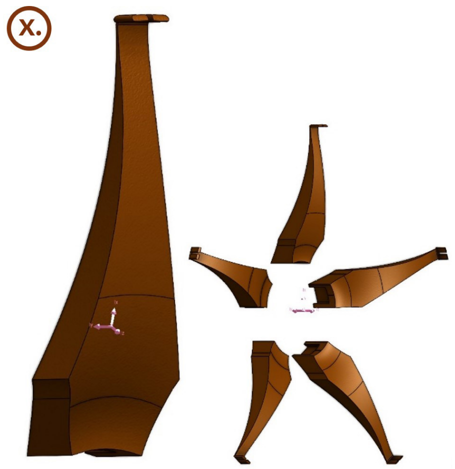


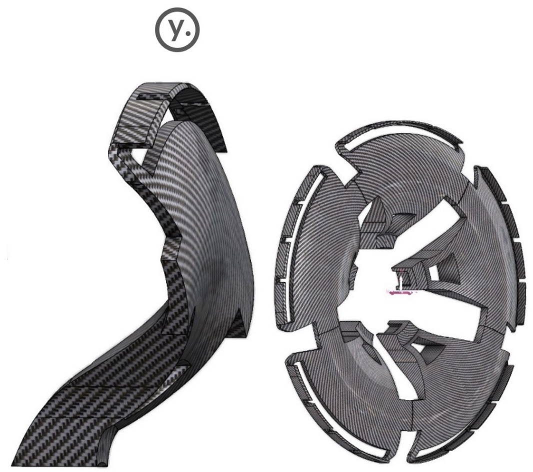
Fig. 53. CSC Series spoke (lighest additional spoke)

Fig. 54. CSP Series spoke (heaviest additional spoke)



If we take this spoke into consideration, 73.5 multiplied by 5 equals to;

367.5 grams in total



If we take this spoke into consideration, 182.2 multiplied by 5 equals to;

911.6grams in total (5-piece set)

Custorim Rim Marking:

17x7.5 5x114.3 ET13 CB73

Fig. 55. CB1 Rim Marking

Addressing Engineering Challenges

Effect of Oscillation:

In this section where the effect of the weight differences of the newly added spokes on the wheel is investigated, I first researched the reason for the occurrence of oscillation effect and how to minimize this effect. Afterwards, I examined snow tire chains that I found from my market research, and thus found a product that I could compare.

Snow chains for passenger vehicles vary in weight between 2 and 7 kilograms. According to my research, although this weight does not significantly affect vibration, it can impact turning dynamics. The reason for the vibration is the irregular contact between the chains and the road rather than unsprung mass.

Fig. 56. Spikes Spider Easy Sport 3 (Snowchainstore, n.d.)

Fig. 57. Chameleon Snow Chain (eBay, n.d.)

Fig. 58. Spikes Spider Sport M. Snow Chain

Braking Performance:

The wheels' rotational inertia is influenced by the weight of the tires. Any variation in this weight may have an impact on how well the tires brake, resulting in uneven brake wear or longer stopping distances if the weight distribution is not level across the tires.

Unbalanced Tires:

The tire may wobble or oscillation may occur when the wheel rotates if the weight change is the result of tire imbalance, which occurs when one part of the tire is heavier than the others. Particularly at faster speeds, this imbalance causes vibrations that are sensed through the steering wheel or the body of the car. The vibrations may cause the vehicle's suspension parts to become strained, uneven tire wear, and decreased fuel efficiency.

Custorim's additional spokes are sold in a 5-piece set, and it is prohibited to attach different types of spokes onto the same base rim!

This prohibition ensures even weight distribution on each rim, thereby preventing any related issues from occurring.

Centre of Mass:

Upon examining the center of mass, I identify that it is precisely located at the same spot as the rim's center.

This alignment ensures that there is no mass imbalance resulting from the weights of the additional spokes.

Fig. 59. CB1 and CSP2 Assembled, showing centre of mass

Suspension Oscillations:

The mass and flexibility of a vehicle's suspension system determine its natural frequency in most situations. This mass rises with increased wheel weight, which may theoretically cause the natural frequency of the system to decrease.

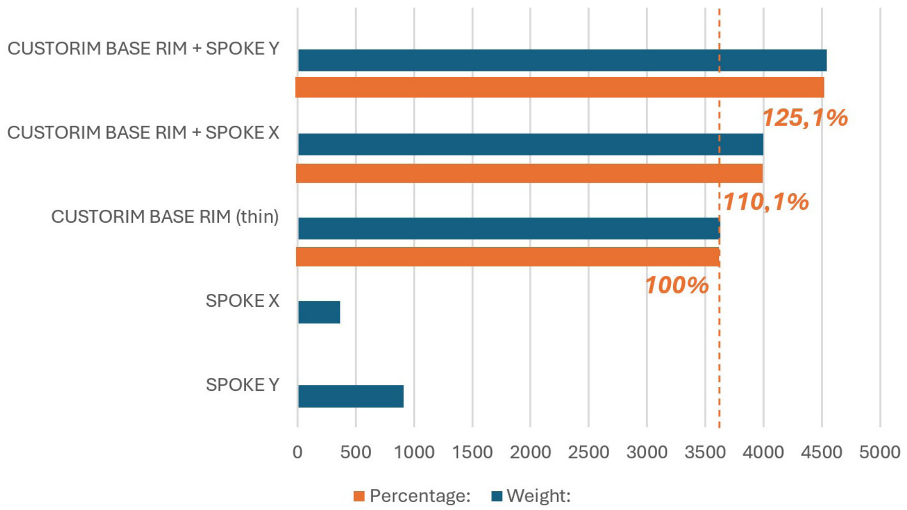
In reality, **a major weight change would be necessary to approach or function close to the resonance frequency of the suspension system.**

Rim Weight Change on Suspension Tolerances:

As a general guideline, automakers usually indicate that suspension systems can tolerate changes in the wheel and tire weight by approximately **1% to 3% of the vehicle's whole weight.** This range is established considering the suspension's and other components' design tolerances.

Weight Change of the Rim:

This percentage tolerance would be significantly lower if we choose a rim with a thick barrel wall, as the weight of such a rim is significantly greater than that of a thinner rim the weight change would be less.

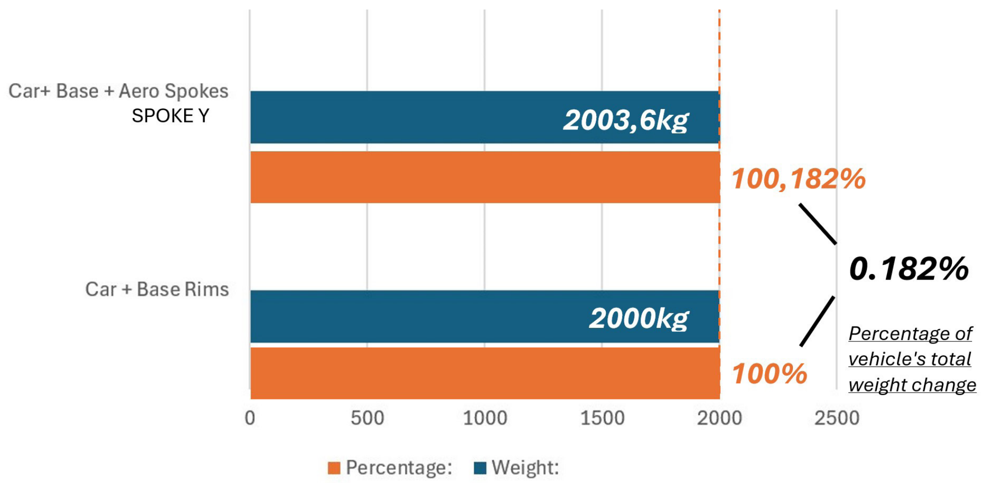


Graph. 60. Weight change of base rim when Spoke X, and Y assembled

Weight Change of the Whole Car:

As we can observe, even when using the heaviest spokes from Custorim, the total weight change of the car is 0.182%, which falls well below the vehicle's suspension tolerance range.

When all 20 (b) spokes assembled on to the car: **3646.5grams**



Graph. 61. Weight change of vehicle's total when all 4 base rims and 20 Additional Spoke Y assembled

Accommodating Diverse Brake Caliper Sizes in Custorim Base Rims

Design Considerations for Performance Vehicles

The design of the CB1 Custorim Base Rim incorporates critical considerations to accommodate the increased braking requirements of performance-oriented vehicles. These vehicles typically necessitate larger brake calipers for superior braking power, which must be factored into the rim design.

Dimensional Analysis and Compatibility Testing

The development process includes a thorough dimensional analysis to ensure that the rim geometry provides sufficient space for various brake caliper sizes. This stage is crucial to guarantee that the rims can accommodate diverse braking systems, facilitating seamless integration without the need for subsequent adjustments.

Strategic Rim Geometry

The CB1 rims feature a deep concavity and positive offset, design choices that are instrumental in offering the necessary clearance for nearly any size of brake calipers. This geometric strategy not only enhances the functionality of the rims concerning brake system compatibility but also maintains the aesthetic appeal, ensuring that the rims meet both performance and design criteria.

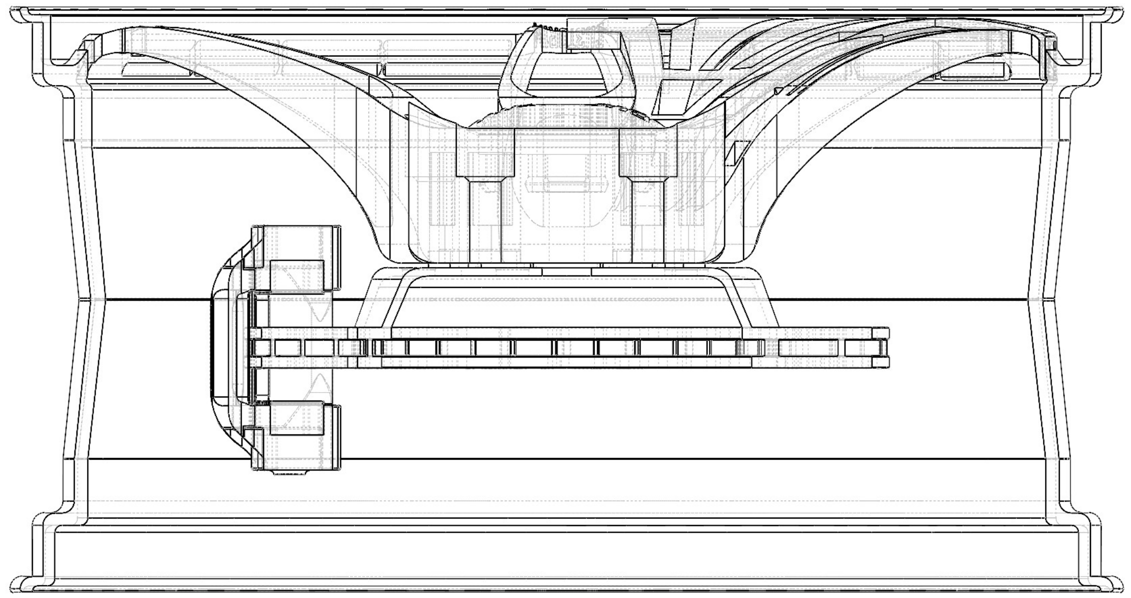


Fig. 62. Cross section view when brake disc and calipper assembled on to the CB1

Fig. 63. Brake disc and calipper assembled on to the CB1+ CSP1

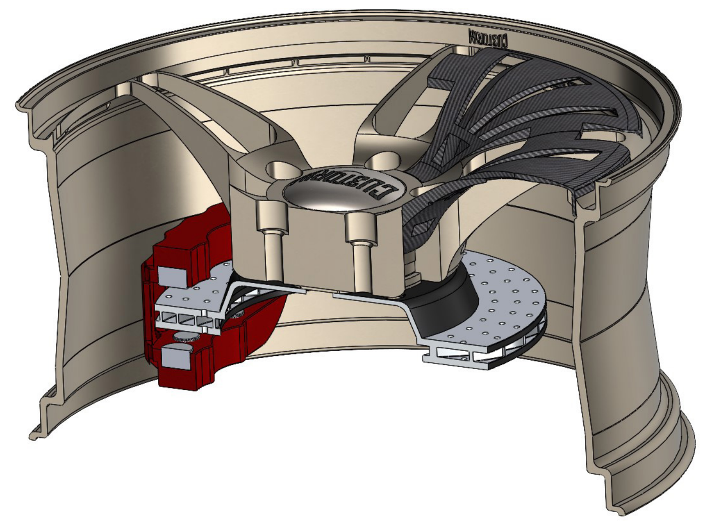
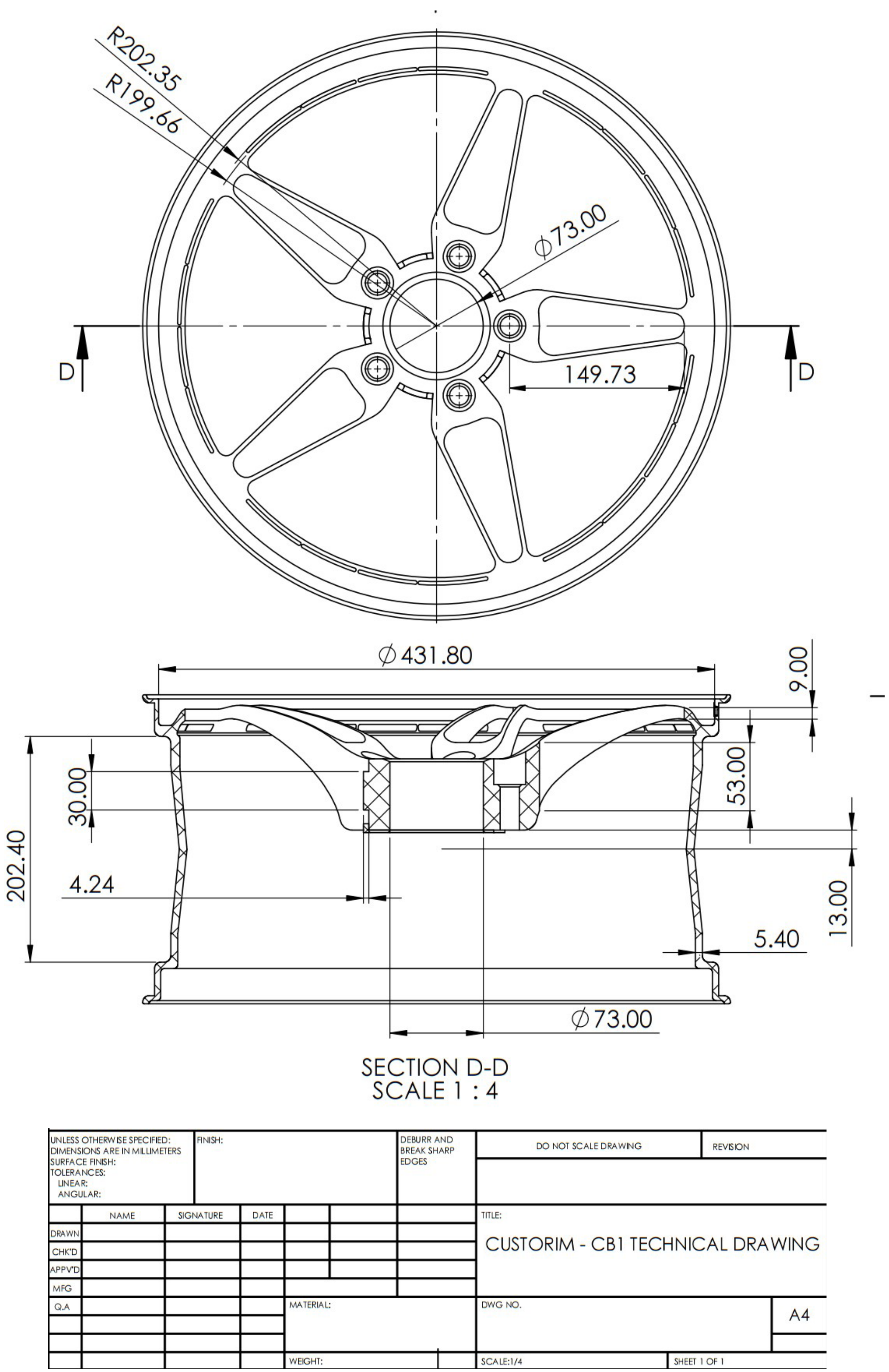


Fig. 64. Cross section view when brake disc and calipper assembled on to the CB1

CB1 - Base Rim Technical Drawing:



3.6 Additional Spoke Desings Iterative Process

Conceptualization and Design Direction

Performance Series – CSP1

Targeted Problem:

By integrating plastic additional spoke solutions into our design, Custorim seeks to achieve performance enhancements such as lower drag coefficients and improved brake cooling efficiency by the assembly of their spokes classified as Performance Series.

This system allows us to enhance aerodynamics and brake cooling without imposing excessive weight on the rims, ensuring that performance enhancements are achieved without compromising the vehicle's agility or braking power due to unsprung mass.

Inspiration:

Fig. 65. Zanini, AERO & AERODINÁMICA ADAPTATIVA (Zanini , n.d.)

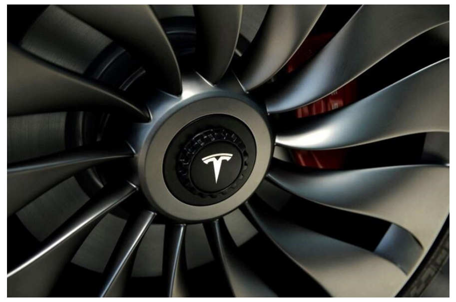


Fig. 66. Tesla Turbine Wheel Concept (luxendary, 2017)

Fig. 67. Jet engine (Arnot, 2019)

Design Engineering Solutions

Key Design Elements:

- Jet fan-inspired cavities designed to enhance brake cooling by mimicking fan functionality.
- A design that maximizes surface coverage to improve aerodynamics significantly.
- A structure engineered to be thin, ensuring the component remains lightweight for optimal performance.

Stages of Development:

1- Sketching

In the initial phase of designing the CSP1, the process began with exploratory sketching. Various cavity designs were experimented with to facilitate air passage and enhance brake cooling effectiveness.

The design strategy aimed to balance aerodynamic benefits with improved brake cooling by maximizing surface coverage and strategically optimizing the positioning and shape of the cavities. This approach ensured that the final design would meet both functional and performance criteria effectively.

Fig. 68. CSP1 concept exploring sketches

2- Initial Concept SolidWorks Digital Model

CAD

In the initial digital modelling phase, my primary goal was to cover the maximum surface area of the rim to achieve optimal aerodynamics. Utilizing SolidWorks, I started the digital modelling by inserting sketches that laid the foundation for my design.

Here are the sketch screenshots on SolidWorks and renderings of the initial model which is nearly fully covered.

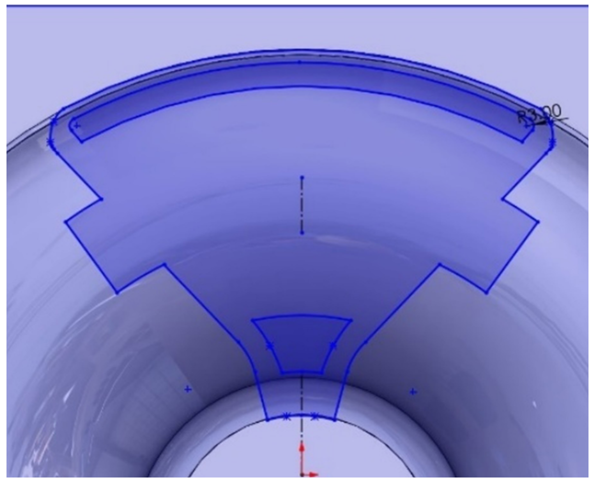


Fig. 69. CSP1 Cut-extrude feature sketch

Fig. 70. CSP1 initial solidworks model renders

3- Final Concept SolidWorks Digital Model

In the final stage, I added three fan-like cavities that I chose from the sketches along the spokes to enhance brake cooling by allowing air to flow through these cavities.

I also added chamfers to the cavities and ensured that the model fits snugly onto the main rim, thus preventing any unwanted air passage through the touching faces of the additional spoke.

Here are the renders and some closeup images of the final CSP1 spoke digital model.

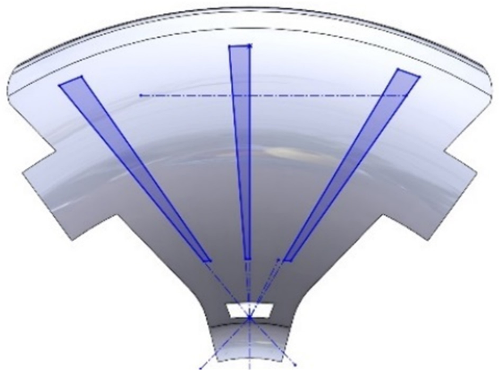


Fig. 71. CSP1 fan cavities, cut extrude feature sketch

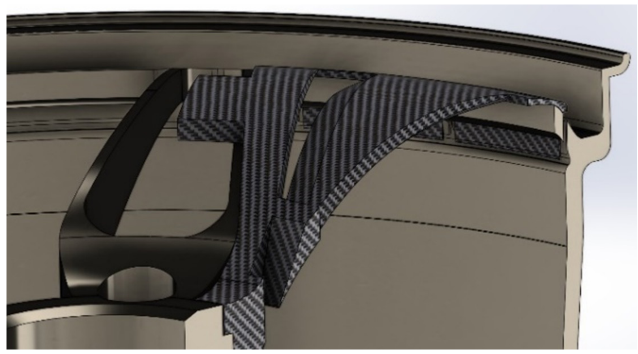


Fig. 72. CSP1 final model assembled on CB1, cross section view

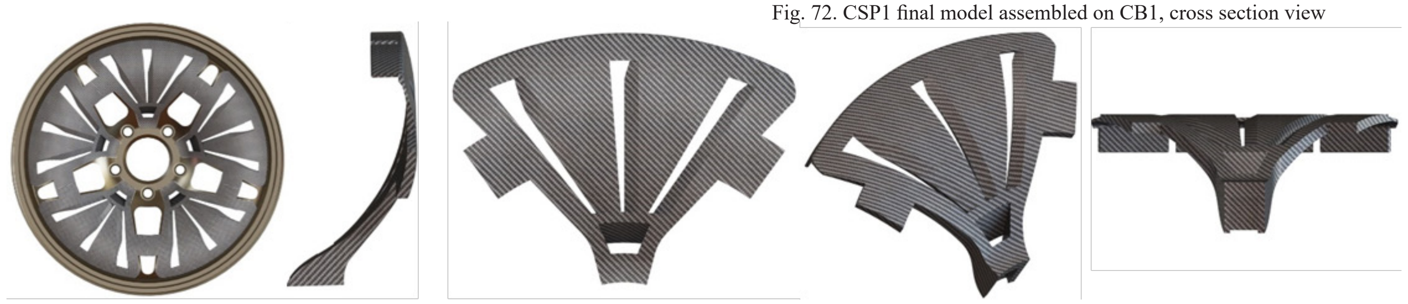


Fig. 73. CSP1 final model assembled on CB1, and renders

Futurist Series – CSF1

Conceptualization and Design Direction

Targeted Design Language:

The Futurist Series, which includes additional spokes from Custorim, features designs that are forward-looking, unseen and futuristic. I aimed to incorporate forms and geometries that are not only trendy but also anticipate future aesthetics on CSF1 spoke design and on the rest of the Futuristic Series additiona spokes.

Inspiration:

I always admired the DS X E-Tense Concept car, which has a total asymmetry on its design with futuristic interior and exterior features, but this concept car was missing a rim design that has the same design language of the whole car.

Given the futuristic and unique design of this concept car, I thought it would be fitting to apply its asymmetrical design language to my CSF1 additional spoke.

Fig. 74. DS X E-Tense Concept Car (www.dsautomobiles.co.uk, n.d.)

Fig. 75. DS X E-Tense Concept Car, side view (www.dsautomobiles.co.uk, n.d.)

Design Engineering Solutions

Key Design Elements:

- Futuristic design.
- Asymmetric geometry inspired by the DS concept car.
- Thin structure, ensuring it is lightweight.
- Curvy, yet sharp design.
- Creative utilization of additional spokes without stress, thanks to the innovative base design.

Stages of Development:

1- Sketching

At the beginning of the CSF1 project, I initiated the design process with a focused sketching session. This stage was dedicated to experimenting with a variety of shapes, geometries, and cavity configurations for the spoke design. My objective was to explore innovative and aesthetically appealing designs.

Each iteration was carefully considered, pushing the boundaries of conventional designs to create a unique spoke that aligns with the futuristic theme of the series.

Fig. 76. CSF1 concept exploring sketches

2- Initial Concept SolidWorks Digital Model

Next, I proceeded with the initial digital modelling of the CSF1. During this phase, I experimented with different cavity sizes and ultimately settled on one.

I refined the design by smoothing out some sharp, unwanted edges with fillets and chamfers, achieving the desired design.

CAD

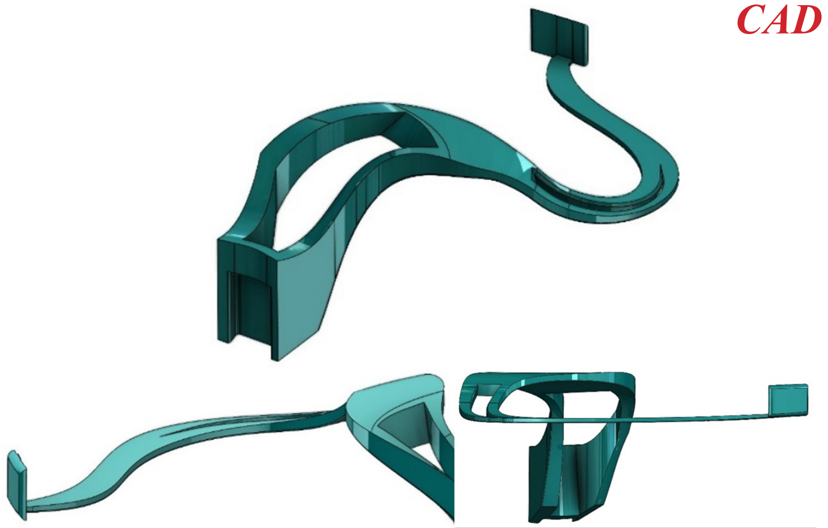


Fig. 77. CSF1 initial solidworks model

3- Final Digital Model Modified for 3D Printing

Following some trials with the CB1 base rim, I implemented final adjustments to the CSF1 additional spoke model to perfect its fitment and refine its design. These adjustments were crucial to ensure that the spoke aligns seamlessly with the base rim, enhancing the overall aesthetic and functional integrity of the system.

Below is the finalized appearance of the CSF1 Futuristic Series, Custorim additional spoke.

Fig. 79. CSF1 final solidworks model

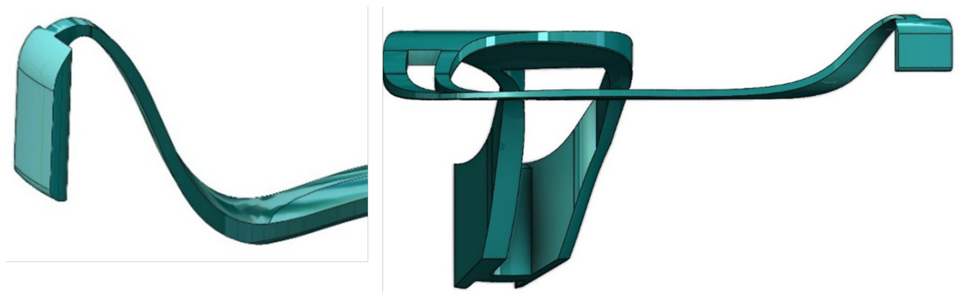


Fig. 78. CSF1 final solidworks model attachment section

Prototyping

4- Physical Prototyping

After all these design processes, I transformed this model into a physical prototype thanks to Resin 3D printer.

I have used this model for physical testing in the later stages and made some corrections for better fitment.

Fig. 80. CSF1 inital 3D print prototype

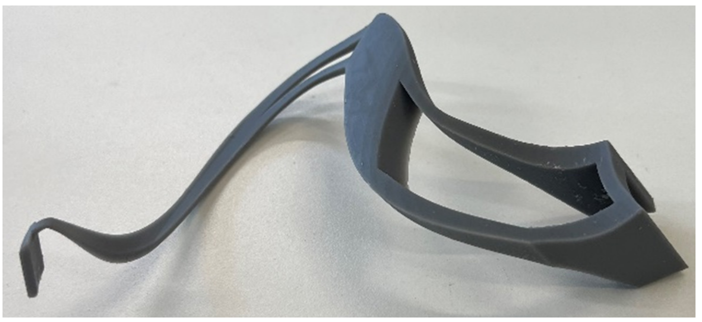
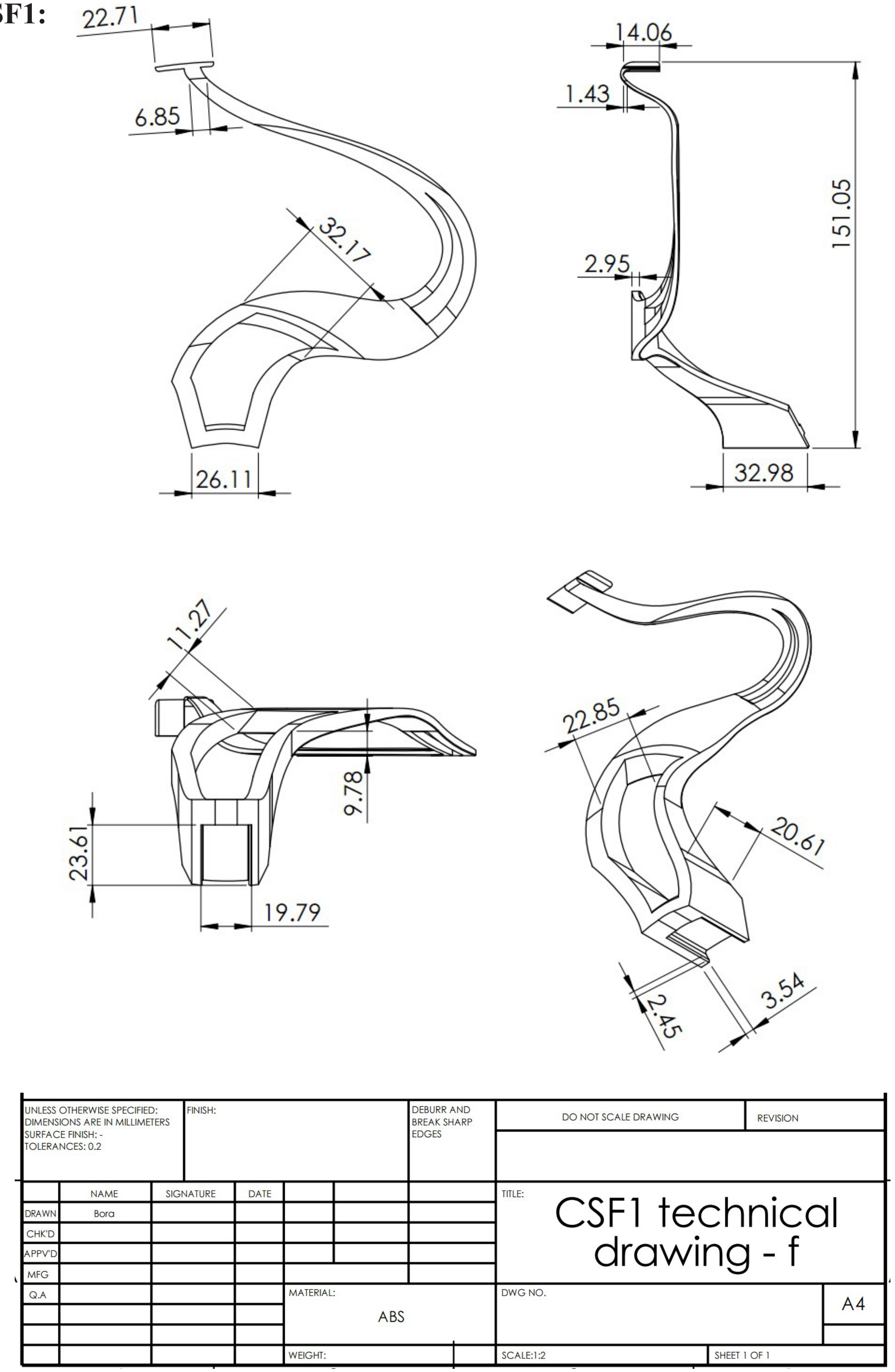


Fig. 81. CSF1 inital 3D print prototype 2

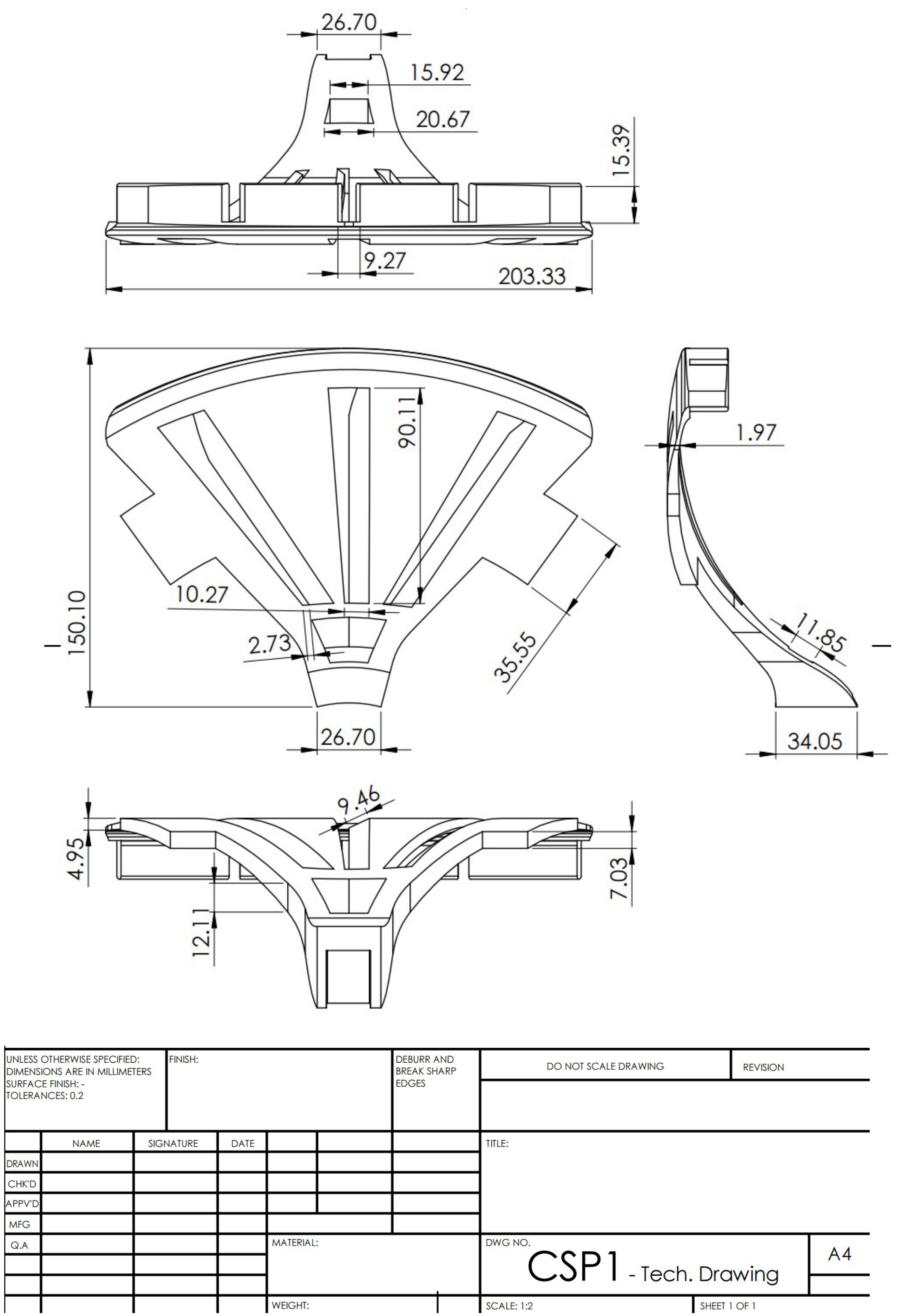
Fig. 81. Finished CSF1 3D print prototype on slice CB1

3.7 Technical Drawings of CSF1 and CSP1:

CSF1:



CSP1:



4. Feasibility Analysis through Quantitative Testing (Solidworks FEA)

FEA

4.1 Test 1 – Thin Barrel Thickness (force on barrel wall)

For this simulation, only the centre support element has been fixed!

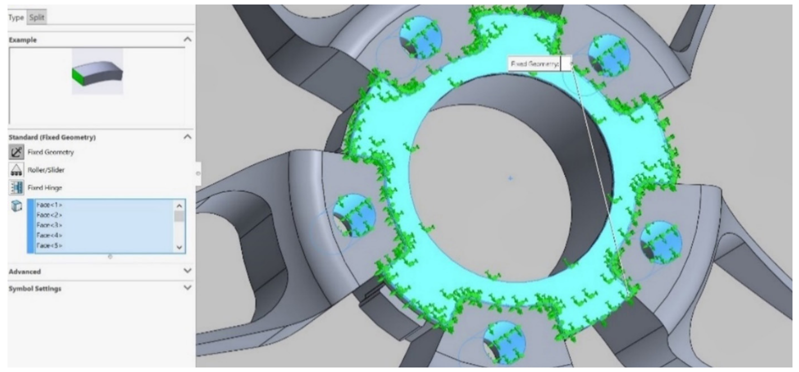


Fig. 82. Fixed Geometries of CB1

Material Selection:

The material selected for this study is the 6061-T6 (SS) Aluminum alloy for the wheel, which has a

Yield Strength of;

275.0 N/mm2

Mass Density;

2700 kg/m3

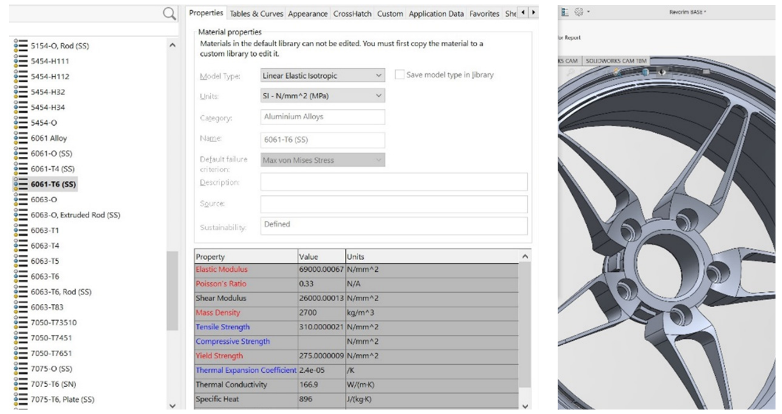


Fig. 83. 6061-T6 Aluminium alloy material properties

Force:

In this simulation, a force of 5000 N was applied to the outer barrel wall of the base rim.

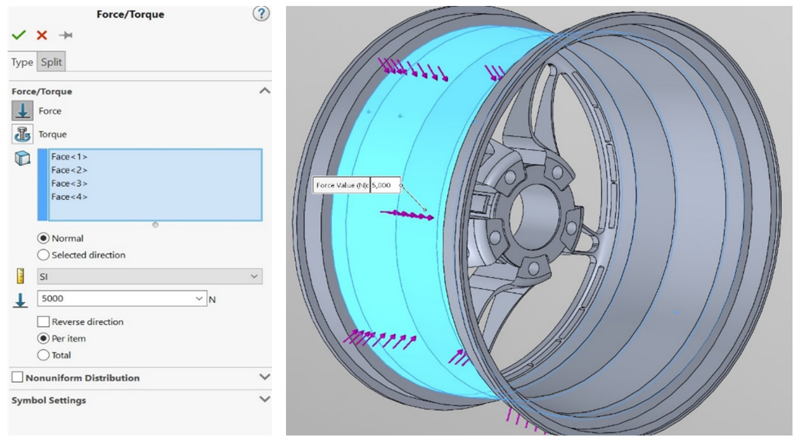


Fig. 84. 5000N in total forces acting on barrel wall, FEA Test 1

Results

After carrying out this simulation, it became obvious that this method is not ideal for assessing the rim's durability.

This is mostly because of how the force was applied to the rim.

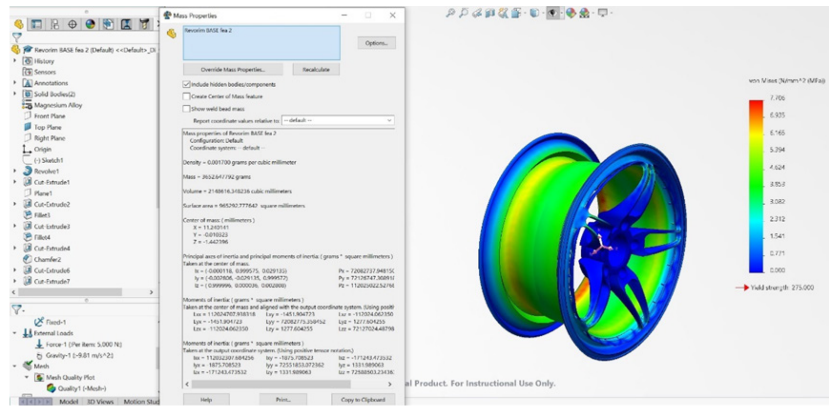
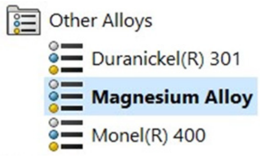


Fig. 85. FEA Test 1, Stress Plot and Mass Properties

4.2 Test 2 – Thick Barrel Wall / 1000 N (force on spoke)(magnesium alloy)

Material Selection:

Magnesium alloy which has a **mass density** value of **1700kg/m3.**



Property	Value	Units
Elastic Modulus	45000	N/mm^2
Poisson's Ratio	0.35	N/A
Shear Modulus	17000	N/mm^2
Mass Density	1700	kg/m^3
Tensile Strength		N/mm^2
Compressive Strength		N/mm^2
Yield Strength		N/mm^2
Thermal Expansion Coefficient	2.5e-05	/K
Thermal Conductivity	160	W/(m·K)
Specific Heat	1000	J/(kg·K)

Fig. 86. Magnesium alloy material properties on Solidworks

Mesh:

The mesh settings are configured at a high level of detail.

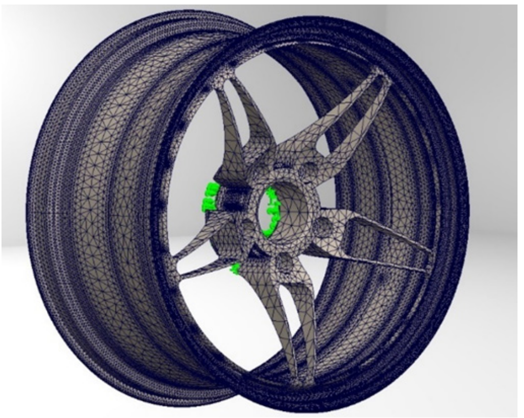


Fig. 87. Mesh of CB1

Fixtures:

An additional support element is located at the back of the centre hub.

For this study, these geometries have been fixed to reflect the typical installation scenario where the rod passes through the centre hole.

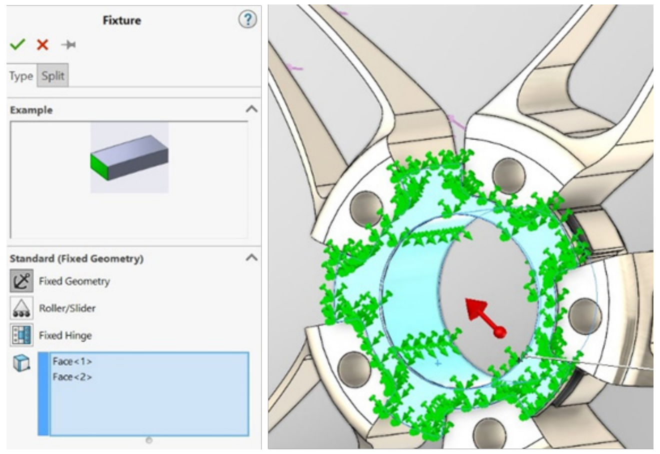


Fig. 88. Fixed geometries for Test 2

Forces:

1000N in total, on one of the main spokes' surfaces.

Why 1000N?

2000kg (weight of the car) / 4
= 500kg (weight affecting each rim)

500kg/5(number of spokes)
= 100kg = 1000N (force affecting each spoke when being static)

+ **Gravity (9.81m/s2)** on top plane

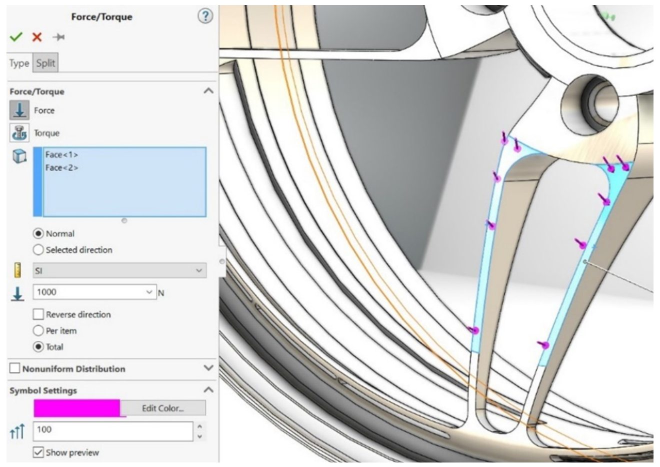


Fig. 89. 1000N in total force on main spoke's surface, FEA Test 2

Results

Stress Plot:

Maximum stress affecting on the model is located at the back of the main spokes which is shown on the image.

maxvon Mises Stress = 21.0

The AZ91 Magnesium Alloy has a yield strength that is ***160–240 MPa***, which is significantly **greater** than the 21 MPa recorded stress.

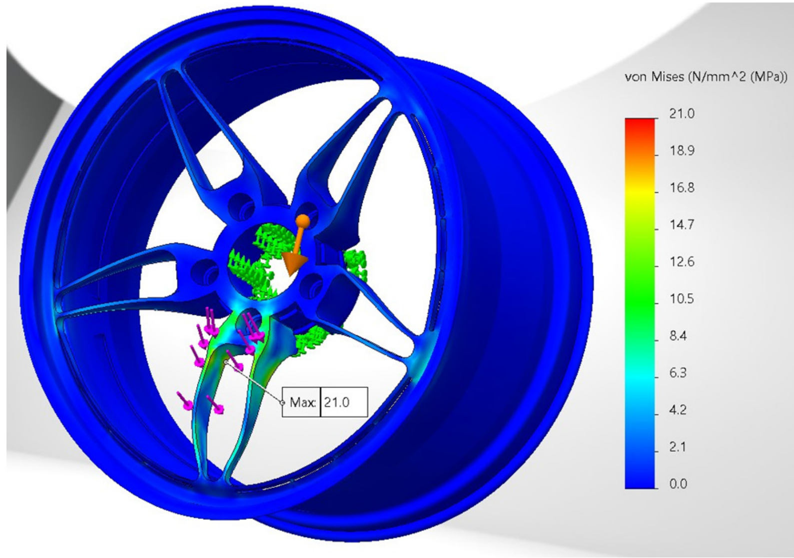


Fig. 90. FEA Test 2, Stress Plot

Displacement:

The ***maximum displacement*** of the model is: ***0.00015 m = 0.15 mm***

Maximum displacement of the model is shown at this image.

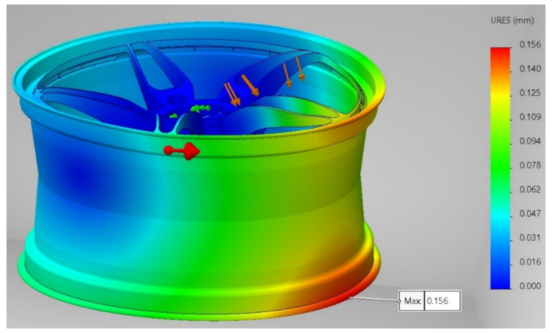


Fig. 91. FEA Test 2, Max Displacement

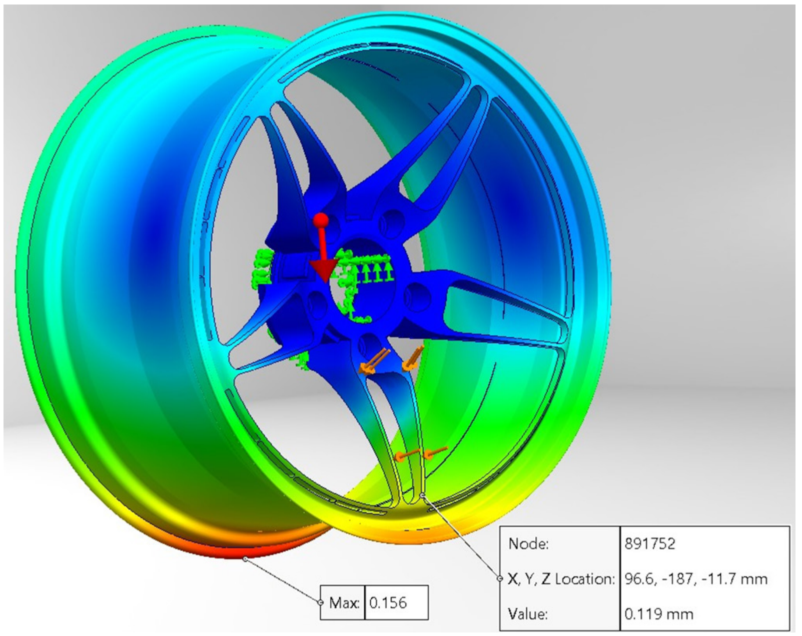


Fig. 92. FEA Test 2, Max Displacement and probe tool on end of main spoke

Strain:

Equivalent strain is max at the back of the main spoke, near where the spokes and the centre hub meet.

Max Equivalent Strain = 0.000340

It is possible to evaluate the total deformation using equivalent strain without having to consider each element of the strain tensor separately.

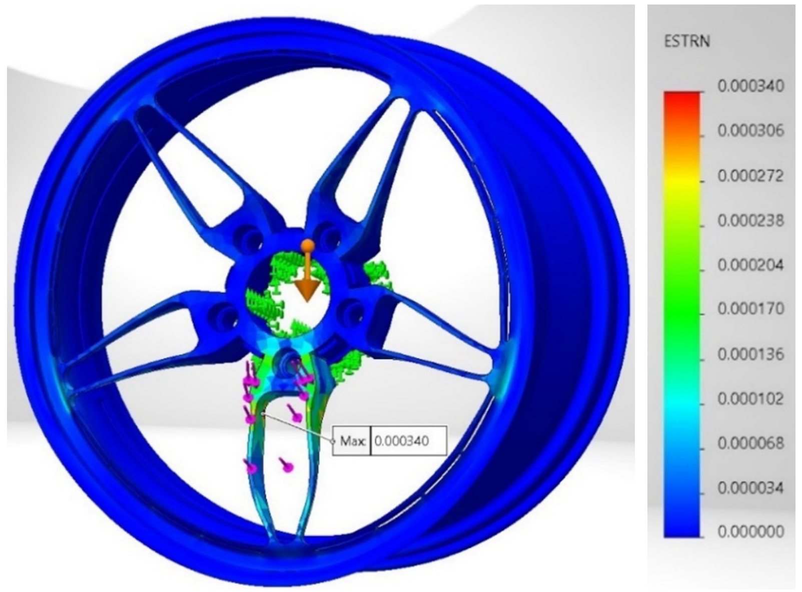


Fig. 93. FEA Test 2, Max Strain

4.3 Test 3 – Thick Barrel Wall / 5000N Force (on spoke) (magnesium)

Fixtures, material selections, mesh settings, and other parameters are consistent with those used in previous studies.

Forces:

5000N in total, on one of the main spokes' surfaces.

Why 5000N?

2000kg (weight of the car) / 4
= 500kg (weight affecting each rim)

500kg = 5000N
5 times more than the force on each rim while being static!

\+ **Gravity (9.81m/s2)** on top plane

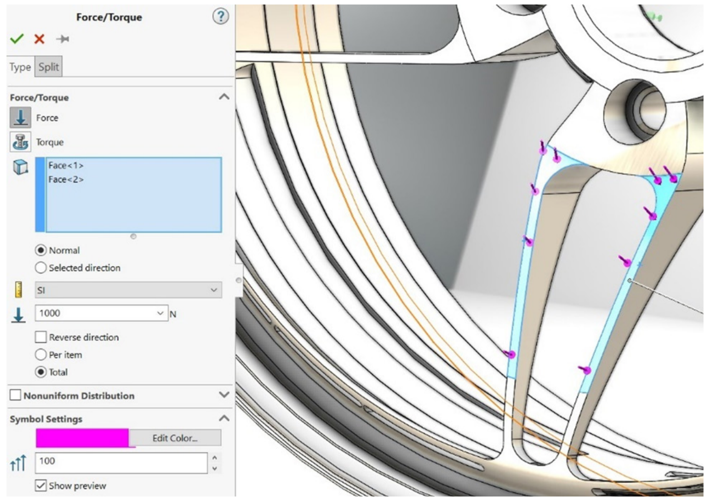


Fig. 94. 5000N in total force on main spoke's surface, FEA Test 3

Results

Displacement:

The model's ***maximum displacement*** is as follows: ***0.0826 (mm) URES***

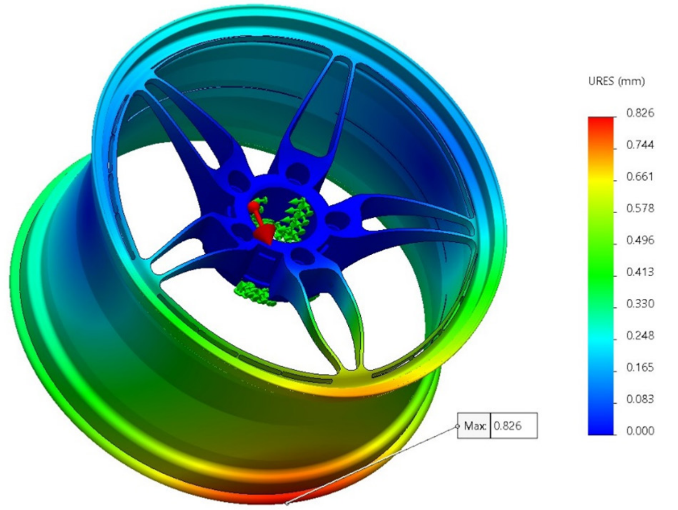


Fig. 95. FEA Test 3, Max Displacement

Displacement Probe:

The **probe tool** has measured a **displacement** of ***0.59 mm*** at the end point of the main spoke.

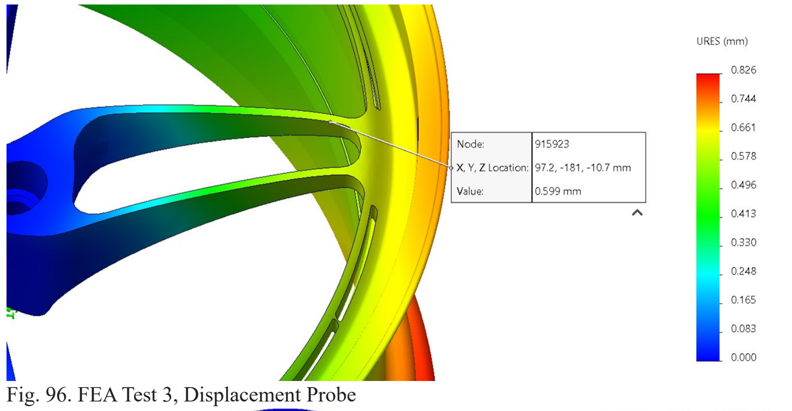


Fig. 96. FEA Test 3, Displacement Probe

Stress Plot:

Maximum stress affecting on the model is located at the back of the main spokes which is shown on the image.

maxvon Mises Stress = 106 MPa

The 6061-T6 Aluminium Alloy has a yield strength of 275MPa, which is significantly **greater than** the 21 MPa recorded stress.

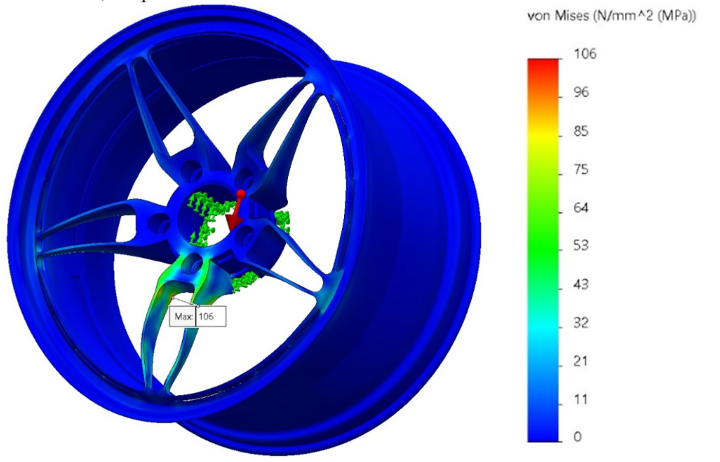


Fig. 97. FEA Test 3, Stress Plot

Stress Probe:

At the specified spot on the back of the spoke, the probe tool measures a stress of ***92 N/mm² (MPa)***, which is **less** than the AZ91 Magnesium Alloy's yield strength.

Therefore, there is **no danger** of a spoke breakage during this simulation.

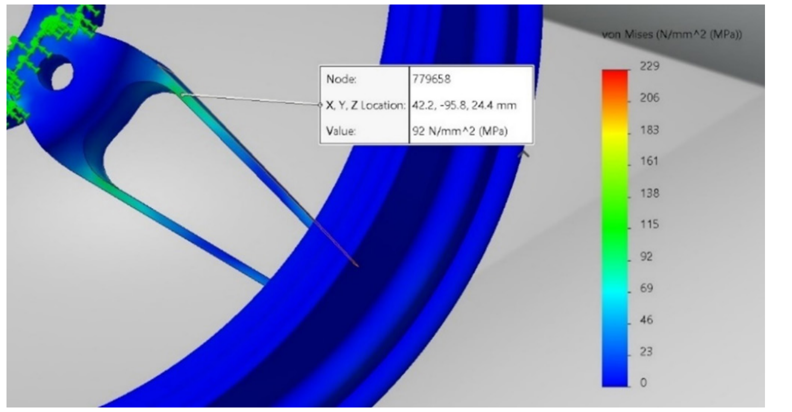


Fig. 98. FEA Test 3, Stress Probe tool on back of the main spoke

Strain:

Equivalent strain is max at the back of the main spoke, near where the spokes and the centre hub meet.

Max Equivalent Strain = 0.00173

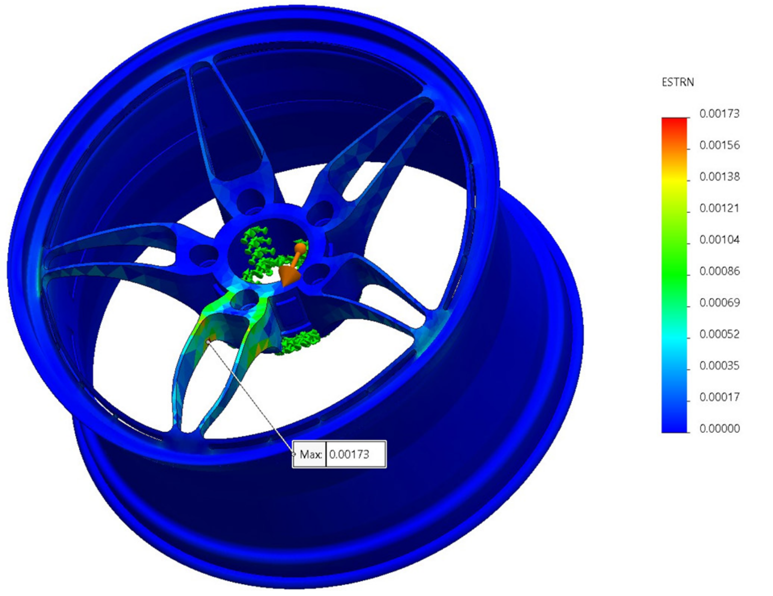


Fig. 99. FEA Test 3, Max Strain

4.4 Test 4 – Thick Barrel Wall / 5000N Force (on spoke) (6061-T6)

Fixtures, mesh settings, and other parameters are consistent with those used in previous studies.

Weight: (6061-T6)

Thick Wall Rim Mass = **7578,95 grams**
(Aluminium Alloy)

Mass Density:

2700 kg/m3

Material Selection:

[6061-T6(SS)] Aluminum Alloy

Yield Strength: ≈ **275MPa**

Tensile Strength: ≈ **310 MPa**

6061 > Is a type of aluminium alloy which has been used for high performance aftermarket wheels because of its high strength, weldability, and other ideal properties.

T6 > Refers to a specific heat treatment. The T6 heat treatment procedure results in a material that has increased yield strength, ultimate tensile strength, and durability when compared to an identical alloy in other temper conditions prior to heat treatment. This advanced treatment enables the use of less material while maintaining the same structural integrity, which contributes to the lightweight and high-performance characteristics of the rim.

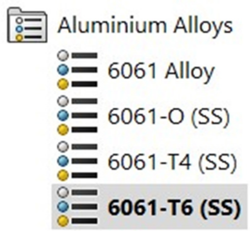


Fig. 100. 6061-T6 Aluminium alloy material properties

Property	Value	Units
Elastic Modulus	69000.00067	N/mm^2
Poisson's Ratio	0.33	N/A
Shear Modulus	26000.00013	N/mm^2
Mass Density	2700	kg/m^3
Tensile Strength	310.0000021	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	275.0000009	N/mm^2
Thermal Expansion Coefficient	2.4e-05	/K
Thermal Conductivity	166.9	W/(m·K)
Specific Heat	896	J/(kg·K)
Material Damping Ratio		N/A

Results

Displacement:

The model's ***maximum displacement*** is as follows:

maxURES(mm) = 0.5 mm
(located at the back of the wheel)

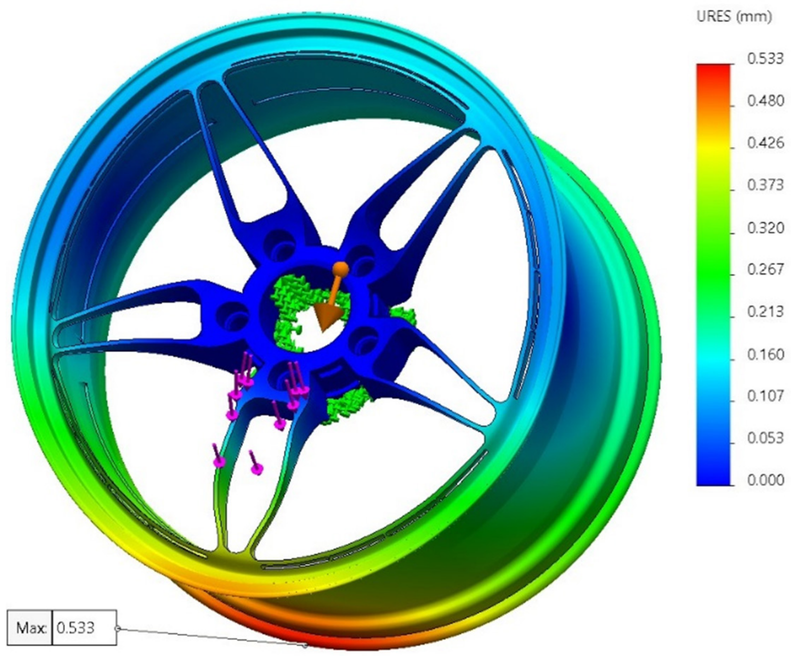


Fig. 101. FEA Test 4, Max Displacement

Displacement Probe:

Displacement at probe = 0.380mm

When probe is located at the top end of the spoke.

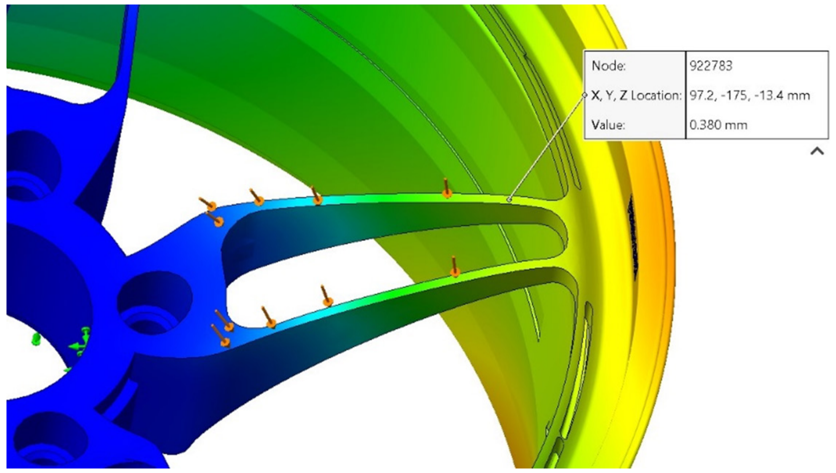


Fig. 102. FEA Test 4, Displacement probe tool on end of main spoke

Stress Plot:

Maximum stress affecting on the model is located at the back of the main spokes which is shown on the image.

maxvon Mises Stress = 106.3 MPa

The 6061-T6 Aluminium Alloy has a yield strength of 275MPa, which is significantly **greater** than the ***21 MPa*** recorded stress.

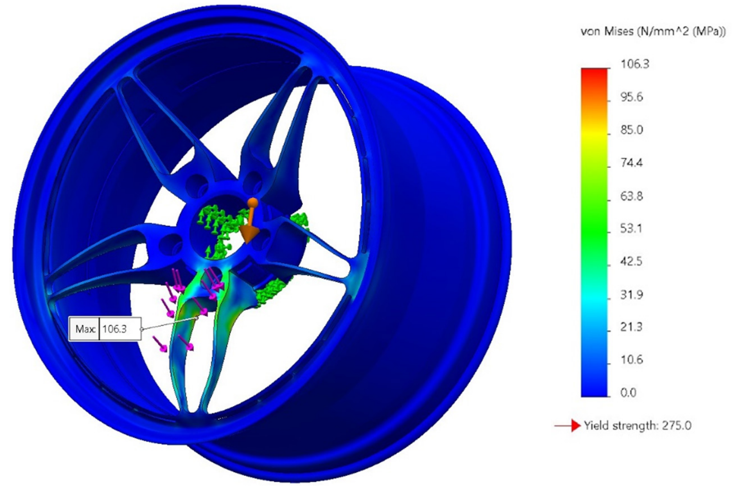


Fig. 103. FEA Test 4, Stress Plot

Stress Probe:

At the specified spot on the top of the spoke, the probe tool measures a stress of ***90.6 N/mm² (MPa)***, which is **less** than the 6061-T6 Aluminium Alloy's yield strength.

There is **no possibilty** of a spoke breakage during this simulation if we take all these data into consideration.

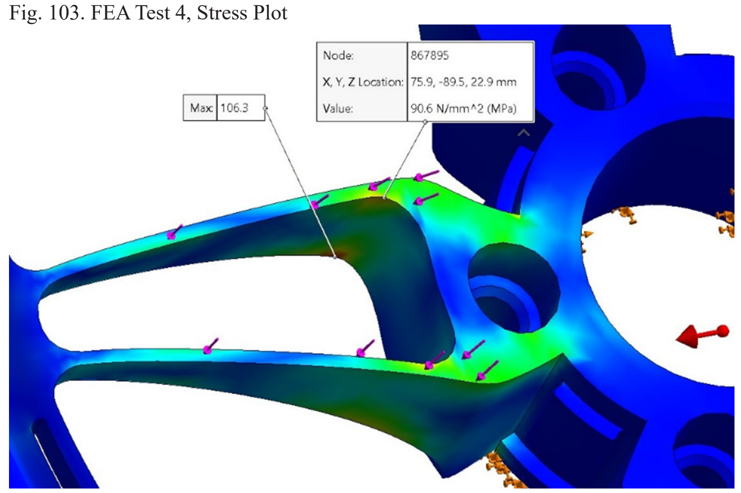


Fig. 104. FEA Test 4, Stress probe tool on the back of the main spoke

275 MPa >106.3 & 90.6 MPA

Strain:

Equivalent strain is max at the back of the main spoke, near where the spokes and the centre hub meet.

Max Equivalent Strain = 0.001

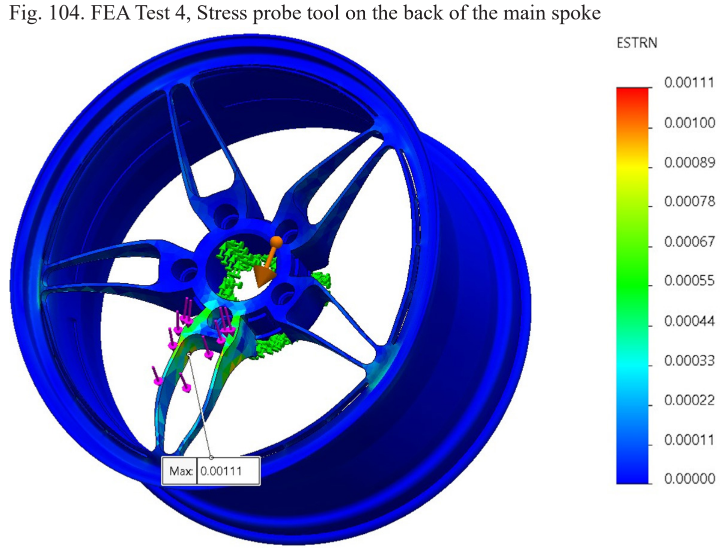


Fig. 105. FEA Test 4, Maximum Strain

4.5 Test 5 – Thick Barrel Wall / 1000N Force (on spoke) (6061-T6)

Fixtures, mesh settings, and other parameters are consistent with those used in previous studies.

Results

Displacement:

The model's ***maximum displacement*** is as follows:

maxURES(mm) = 0.09 mm

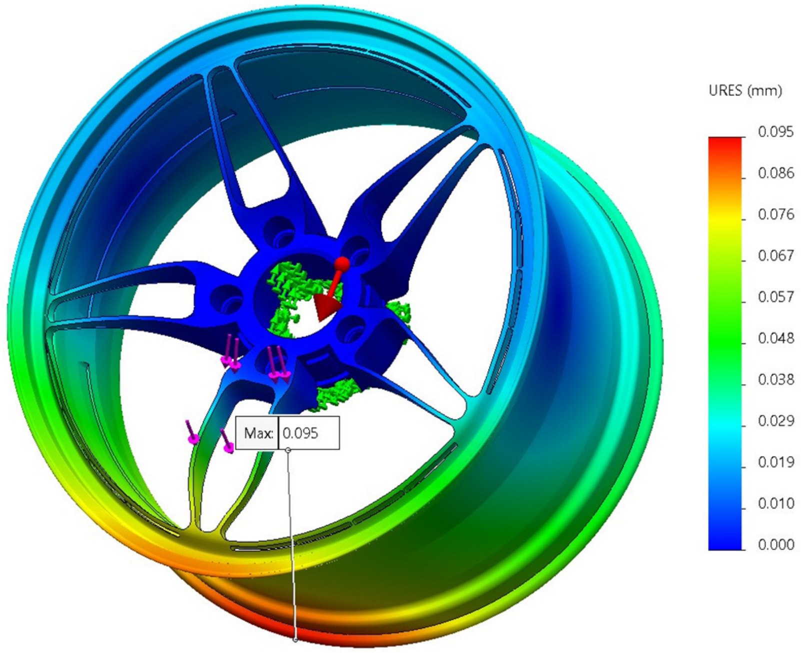


Fig. 106. FEA Test 5, Maximum Displacement

Displacement Probe:

Displacement at probe = 0.007 mm

When probe is located at the top end of the spoke.

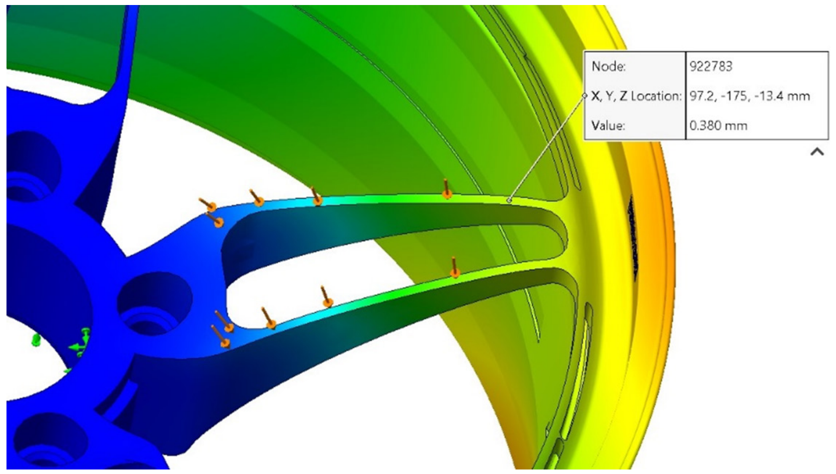


Fig. 107. FEA Test 5, Displacement probe tool on end of main spoke surface

Stress Plot:

Maximum stress affecting on the model is located at the back of the main spokes which is shown on the image.

maxvon Mises Stress = 20.9 MPa

The 6061-T6 Aluminium Alloy has a yield strength of 275MPa, which is significantly **greater** than the 21 MPa recorded stress.

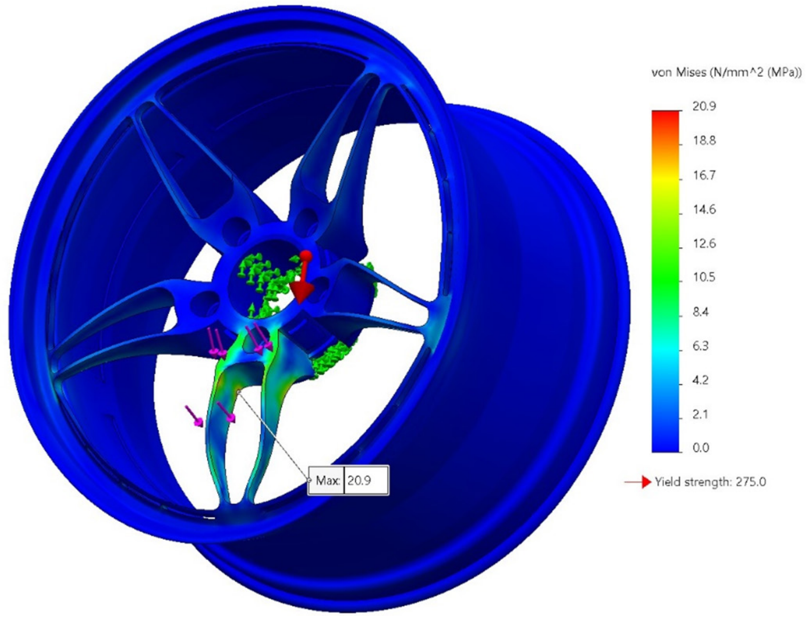


Fig. 108. FEA Test 5, Stress Plot

Stress Probe:

At the specified spot on the top of the spoke, the probe tool measures a stress of ***17.9 N/mm² (MPa)***, which is less than the 6061-T6 Aluminium Alloy's yield strength.

There is **no possibilty** of a spoke breakage during this simulation.

275 MPa >20.9 & 17.9 MPA

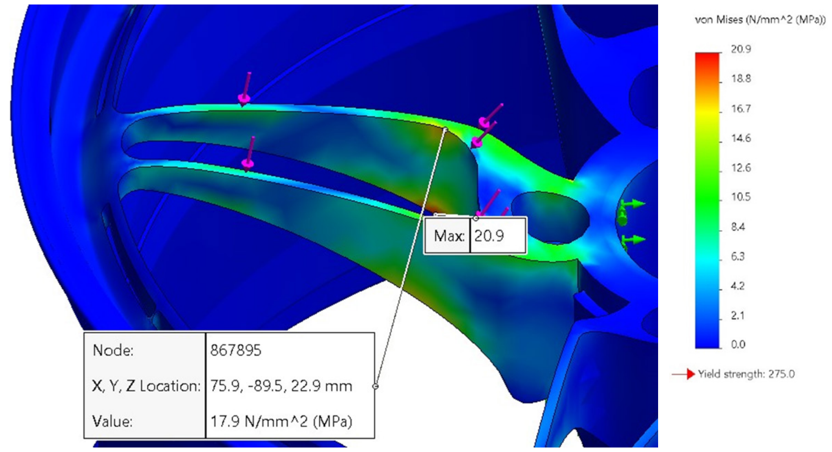


Fig. 109. FEA Test 5, Stress Probe

Strain:

Equivalent strain is max at the back of the main spoke, near where the spokes and the centre hub meet.

Max Equivalent Strain = 0.0002

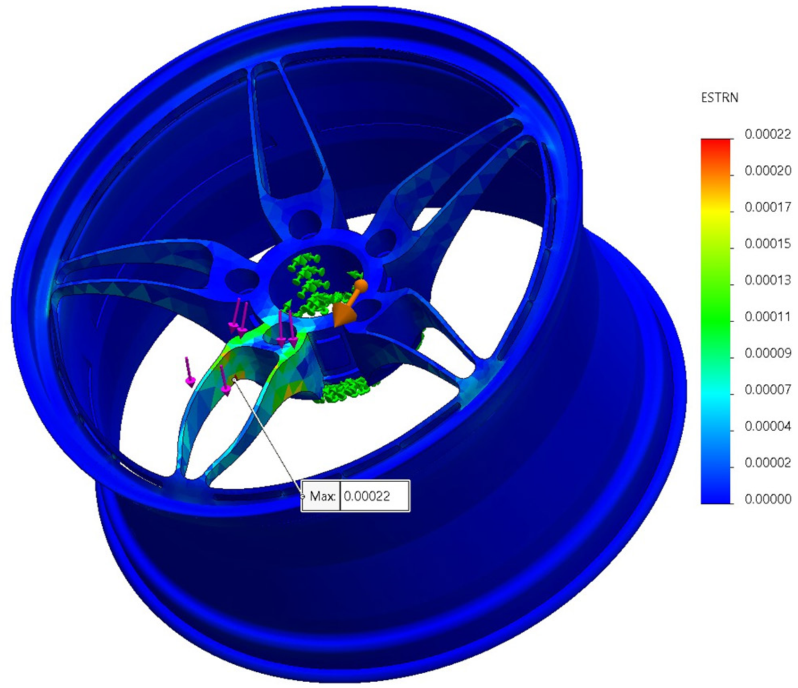


Fig. 110. FEA Test 5, Maxium Strain

Strain Probe:

Equivalent Strain on probe = 0.00019

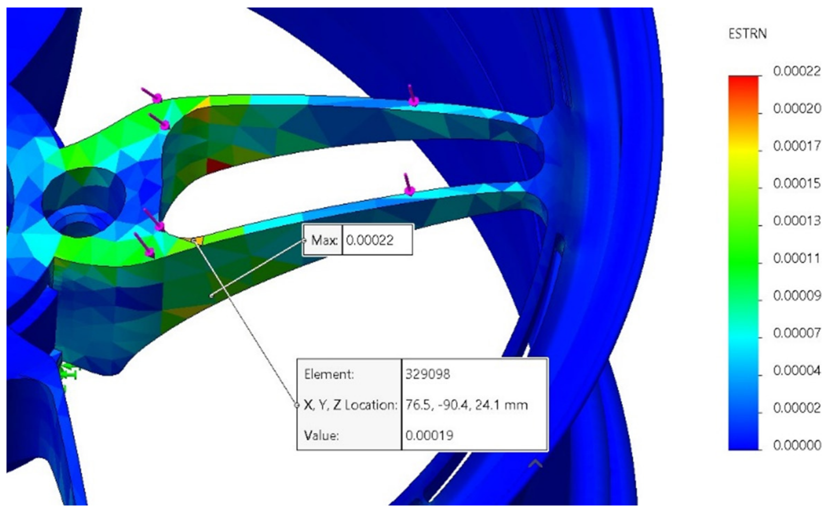


Fig. 111. FEA Test 5, Strain Probe

4.6 Test 6 – Thick Barrel Wall / 5000N Force (rotational) (magnesium)

Fixtures, mesh settings, and other parameters are consistent with those used in previous studies.

Forces:

5000N in total acting upon all of the spokes.

1000 rpm - Centrifugal force at the center

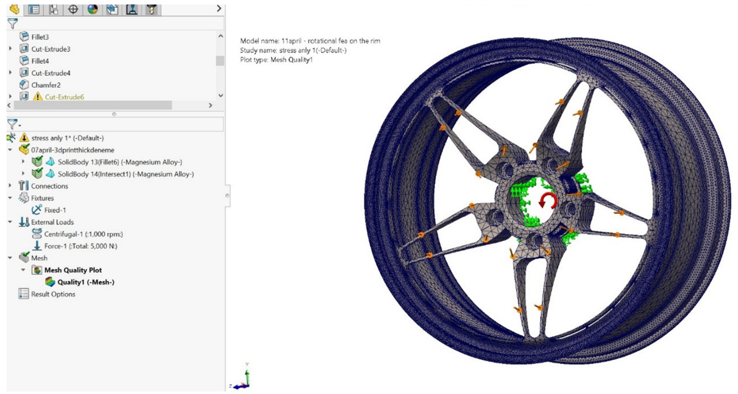


Fig. 112. 5000N total on main spokes, 1000rpm centrifugal force FEA Test 6

Results

Displacement:

The model's ***maximum displacement*** is as follows:

maxURES(mm) = 0.16 mm

Model name: 11april - rotational fea on the rim
Study name: stress only 1(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 293.529

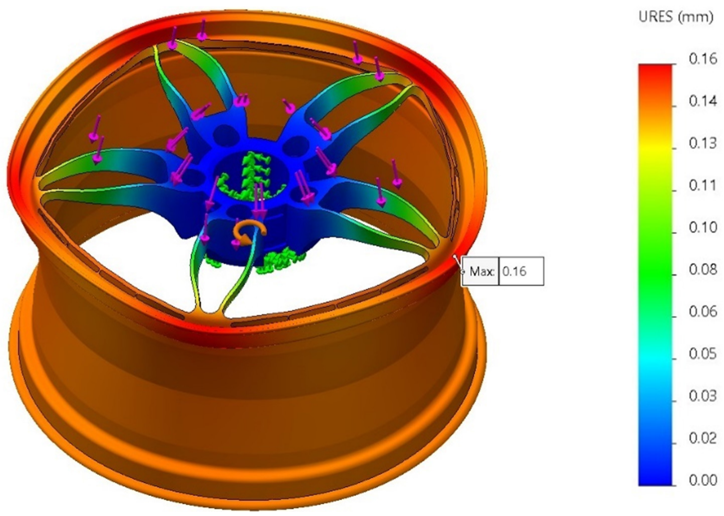


Fig. 113. Maxiumum Displacement, FEA Test 6

Strain:

Max Equivalent Strain = 0.0003

Model name: 11april - rotational fea on the rim
Study name: stress only 1(-Default-)
Plot type: Static strain Strain1
Deformation scale: 1

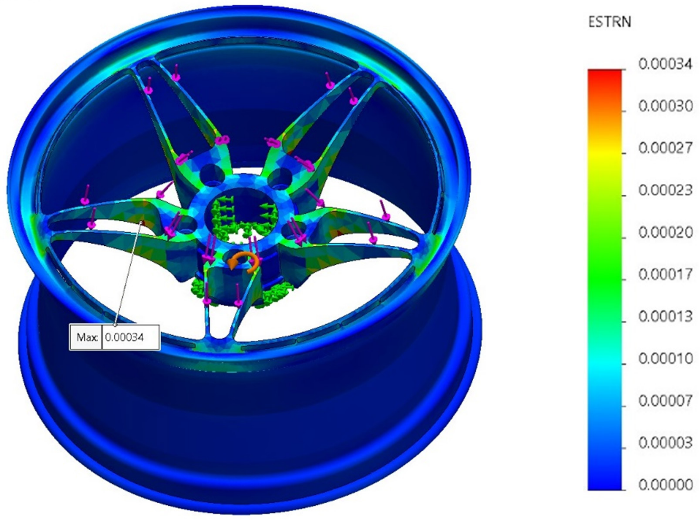


Fig. 114. Maxiumum Strain, FEA Test 6

Stress Plot:

maxvon Mises Stress = 20.7 MPa

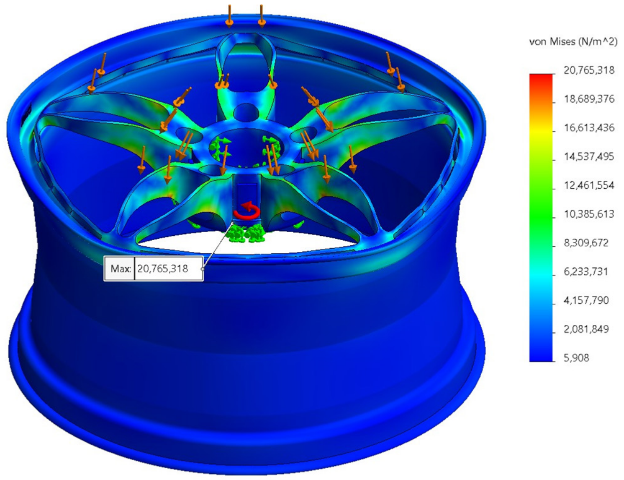


Fig. 115. Stress Plot, FEA Test 6

4.7 Understanding Results, Material Properties & Comparison

The maximum von Mises stress, a crucial parameter in engineering used to identify the beginning of yielding, is a measure of stress.

The Yield Strength of a material is the greatest stress it can endure without experiencing irreversible deformation. Past this point, the material will not return to its initial form.

The Ultimate Tensile Strength refers to the maximum stress that a material can withstand before it starts to neck, signalling an approaching occurrence of failure.

Understanding these characteristics is essential for enhancing the structure of materials, such as those employed in the CB1 base rim, to guarantee they achieve optimum resilience and strength while minimising material consumption.

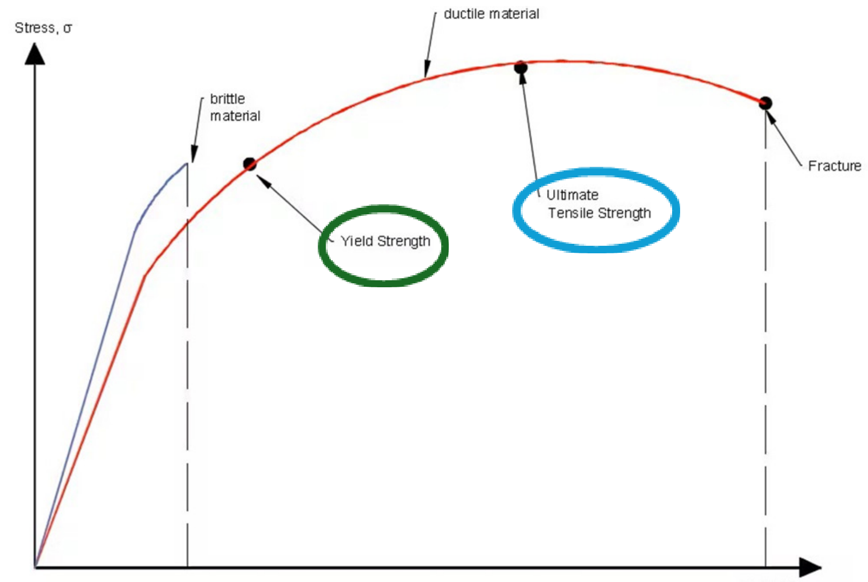


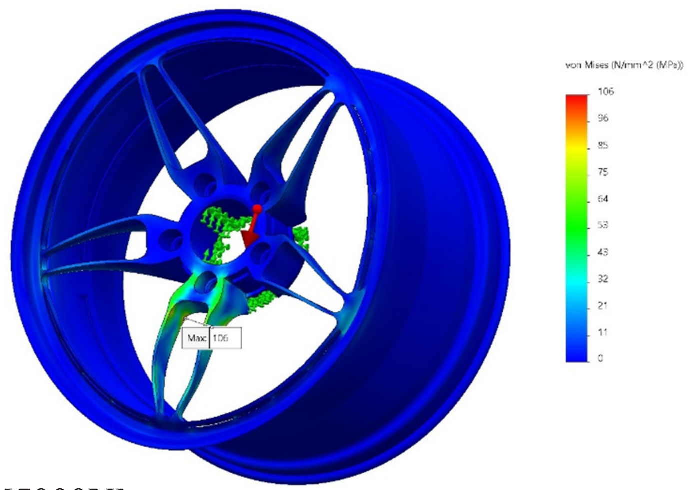
Fig. 116. Stress-strain curve with yield-strength (Team Xometry, 2023)

In both scenarios analyzed, it is apparent that the maximum stress exerted on the spokes does not lead to breakage. This resilience is attributed to the enhanced properties of magnesium alloys, which maintain their strength even without additional heat treatment.

In **5000N** testing (5x); ***106 MPa***

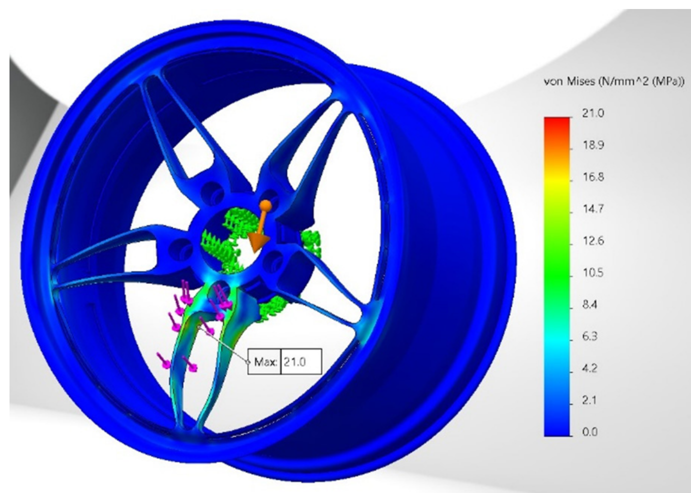
In **1000N** testing; ***21 MPa***

Both less than the yield strength of AZ91 which is around 160-240 MPa!



[5000N]

Fig. 117. Maxiumum Stress, 5000N on CB1 magnesium



[1000N]

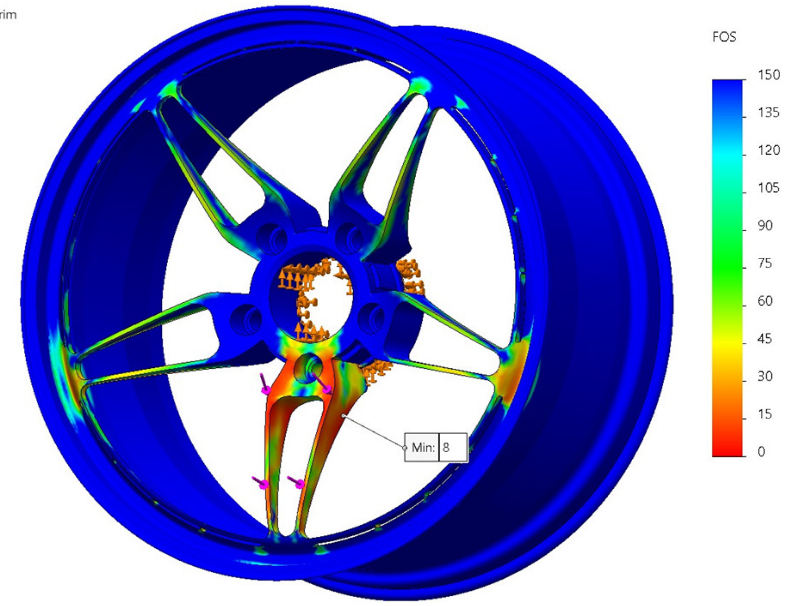
Fig. 118. Maxiumum Stress, 1000N on CB1 magnesium

4.8 Factor Of Safety (FoS)

If any region of the rim exhibits a Factor of Safety (FoS) less than 1, it signifies that part of the model is likely to fail under the applied load conditions.

In ***each of these simulations***, the ***FoS values exceed 1!***

AZ91(Magnesium Alloy) – 1000N:



Min FoS = 7.6

Yield Strength: 160 MPa

Fig. 119. FoS Value of CB1, AZ91 magnesium, 1000N Force

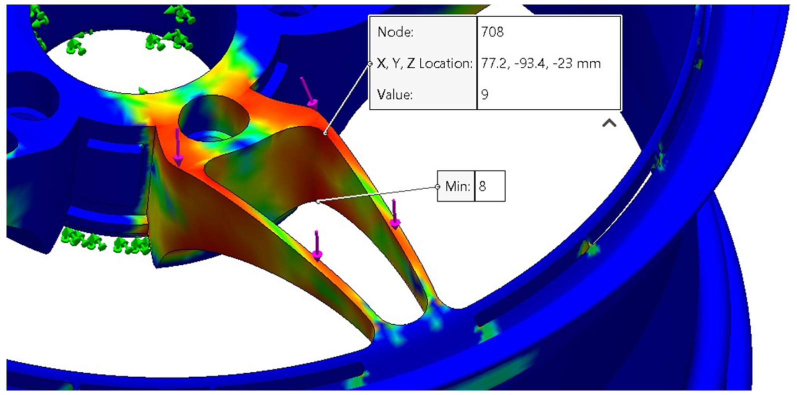


Fig. 120. FoS Probe Value of CB1, AZ91 magnesium, 1000N Force

AZ91(Magnesium Alloy) – 5000N:

Min FoS = 1.5

Yield Strength: 160 MPa

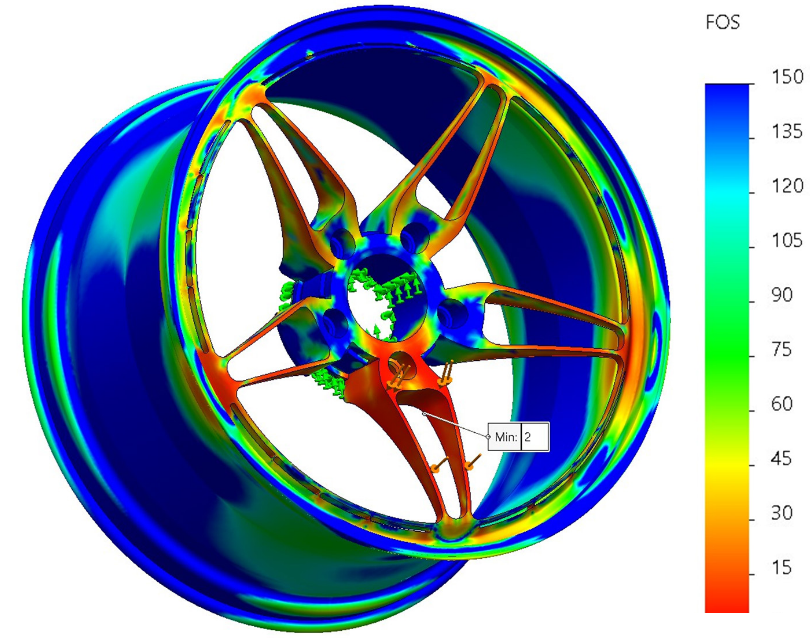


Fig. 121. FoS Value of CB1, AZ91 magnesium, 5000N Force

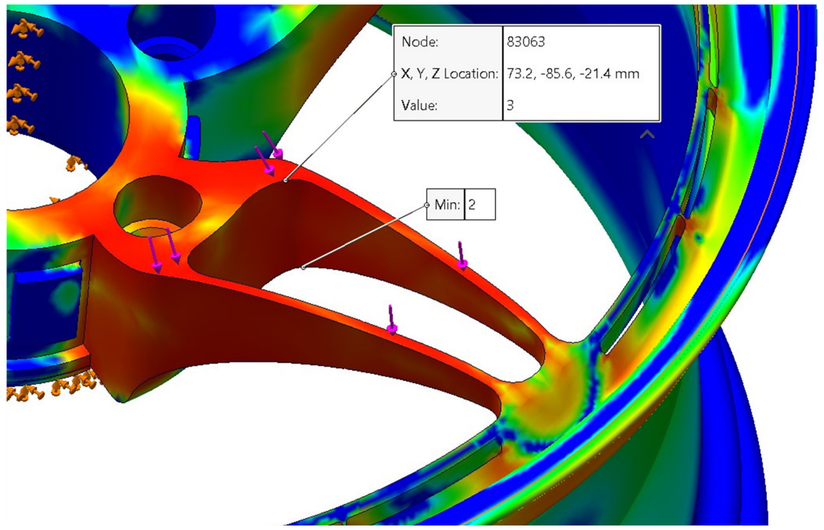
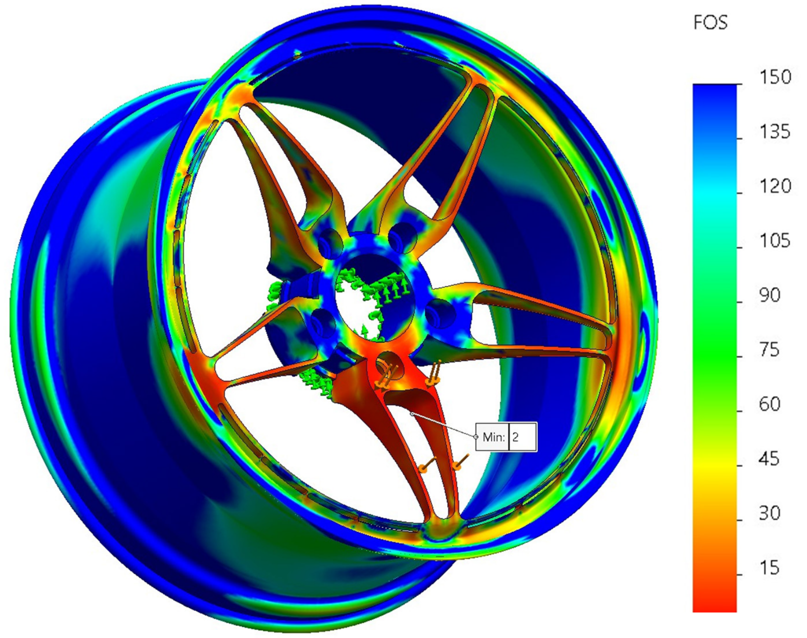


Fig. 122. FoS Probe Value of CB1, AZ91 magnesium, 5000N Force

Elektron 21(Magnesium Alloy) – 1000N



Min FOS = 8.1

Yield Strength: 170 MPa

Fig. 123. FoS Value of CB1, Elektron 21 magnesium, 1000N Force

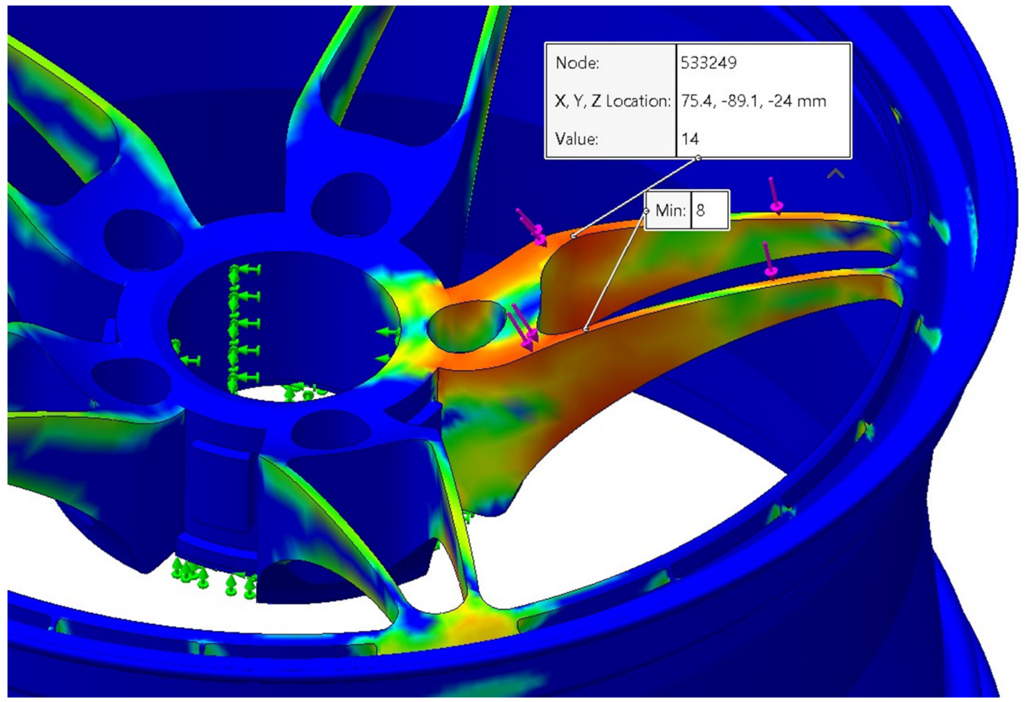
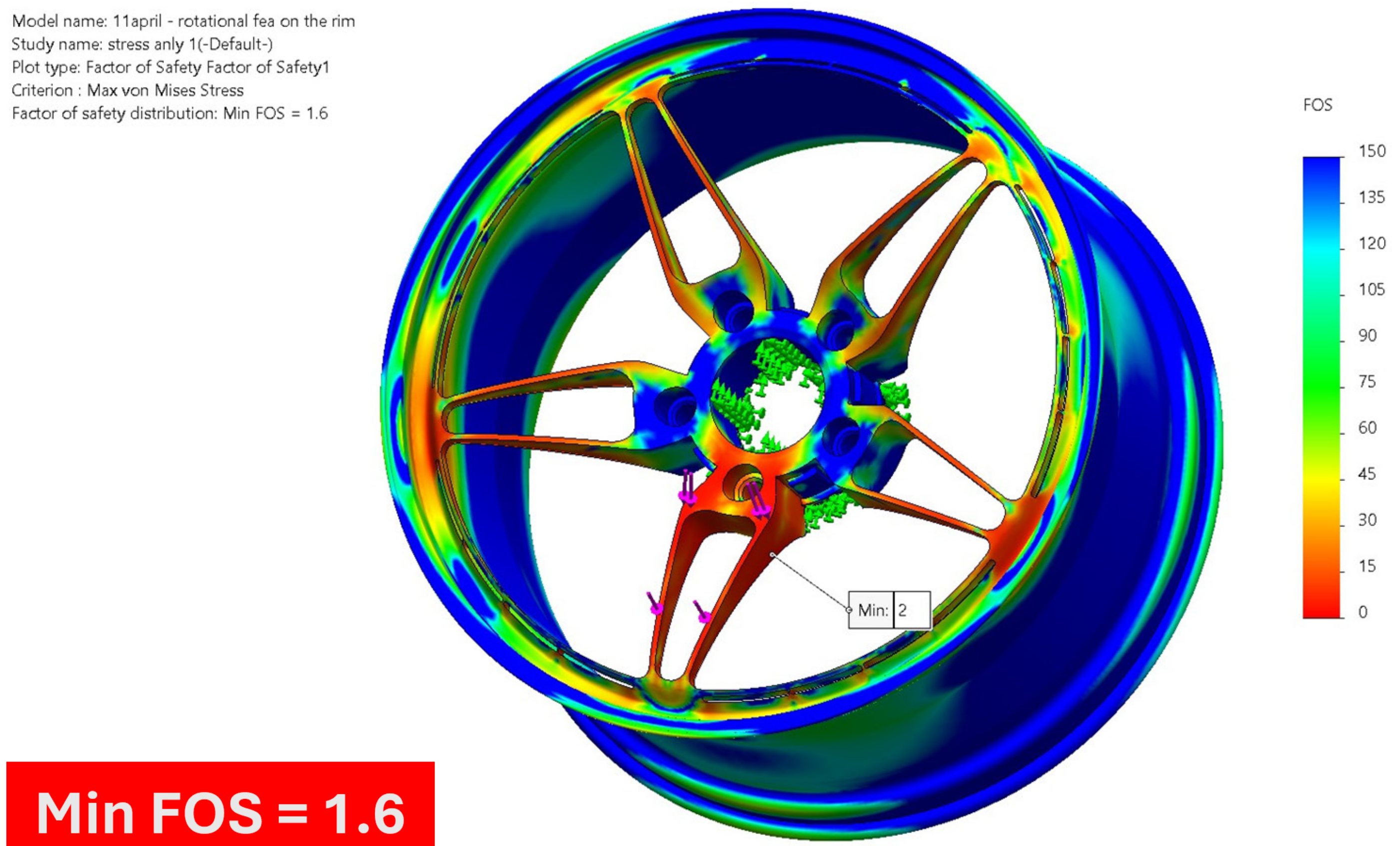


Fig. 124. FoS Probe Value of CB1, Elektron 21 magnesium, 1000N Force

Elektron 21(Magnesium Alloy) – 5000N



Min FOS = 1.6

Yield Strength: 170 MPa

Fig. 125. FoS Value of CB1, Elektron 21 magnesium, 5000N Force

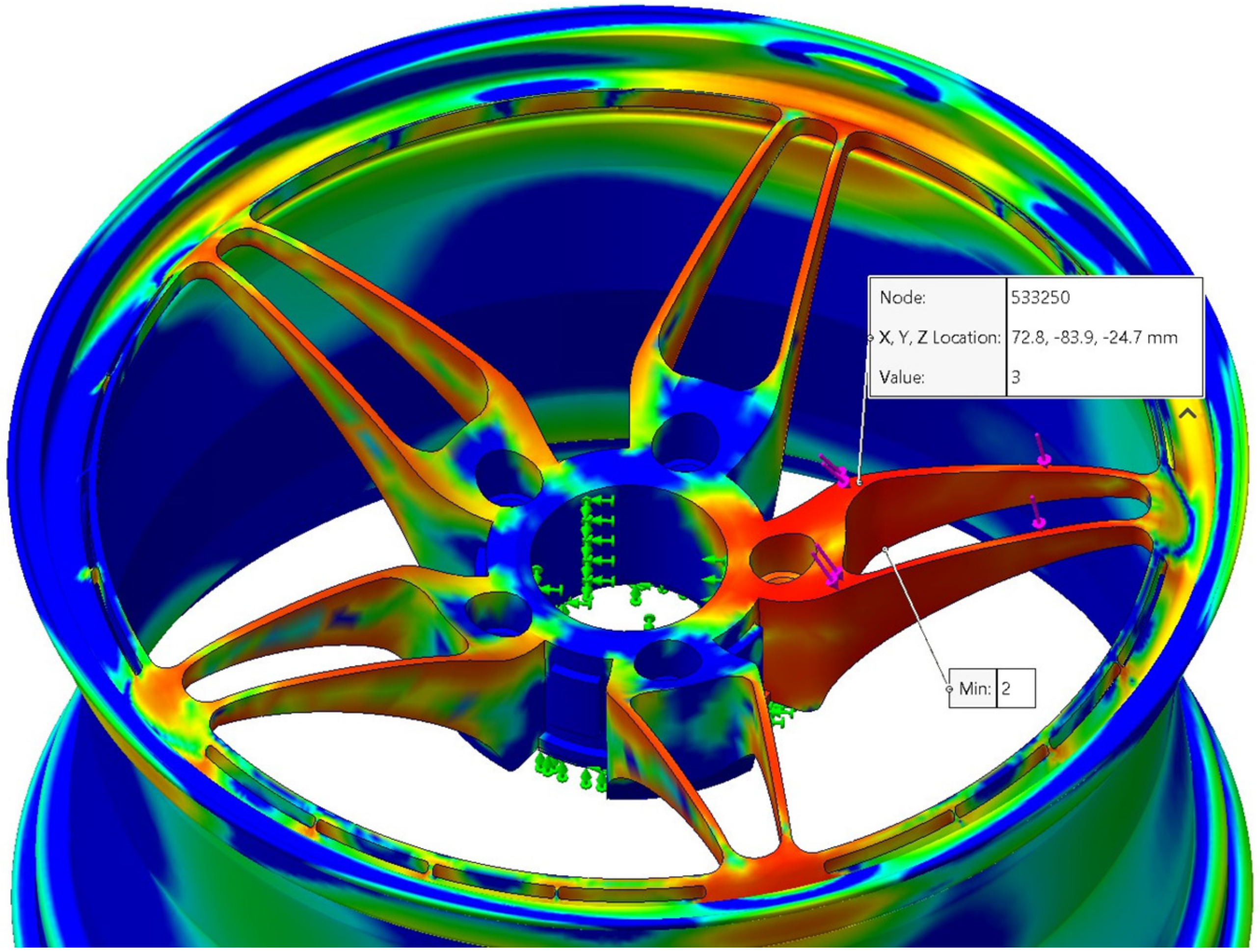


Fig. 126. FoS Probe Value of CB1, Elektron 21 magnesium, 5000N Force

6061-T6(Aluminium Alloy) – 1000N

Min FOS = 13

Yield Strength: 275 MPa

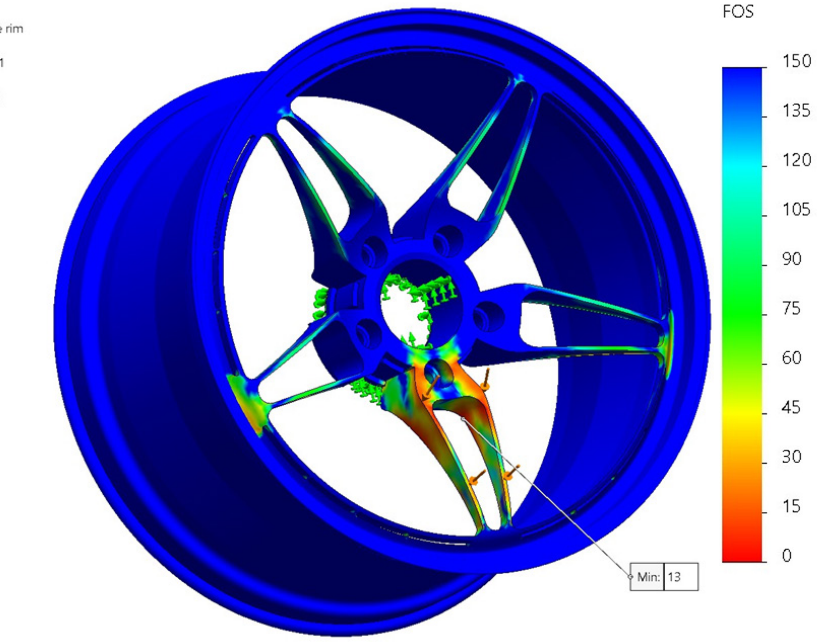


Fig. 127. FoS Value of CB1, 6061-T6 aluminium, 1000N Force

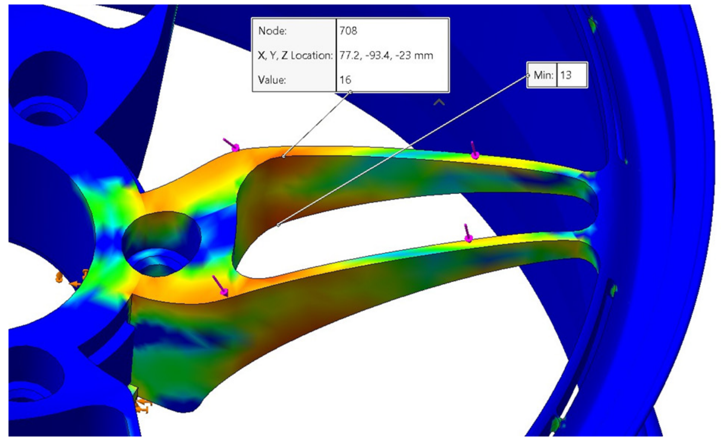


Fig. 128. FoS Probe Value of CB1, 6061-T6 aluminium, 1000N Force

6061-T6(Aluminium Alloy) – 5000N

Min FOS = 2.6

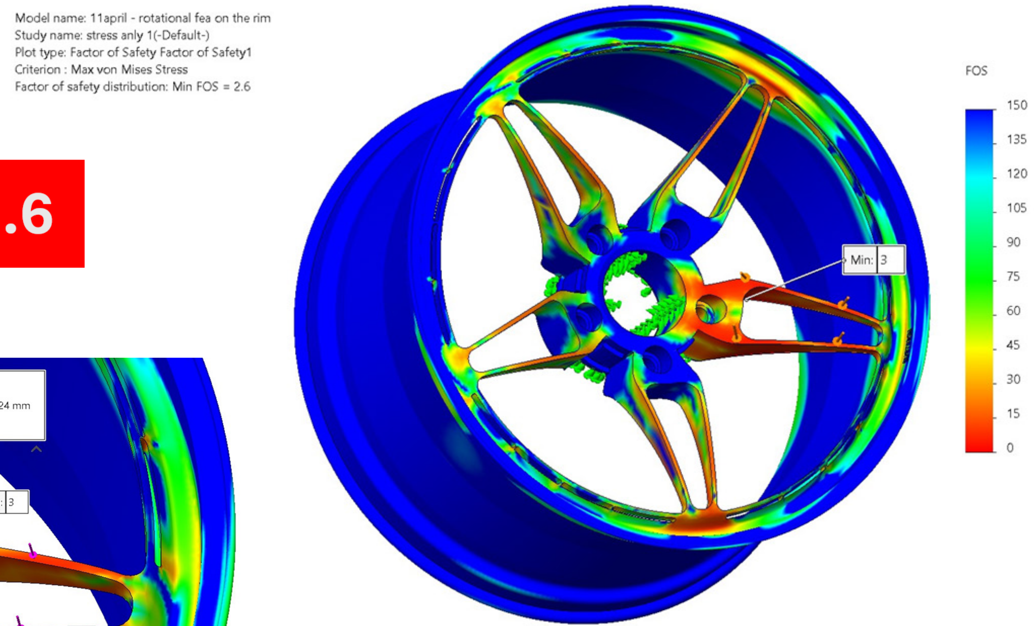


Fig. 129. FoS Value of CB1, 6061-T6 aluminium, 5000N Force

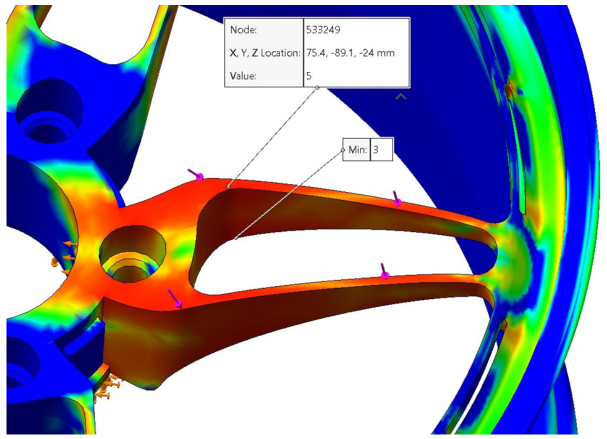


Fig. 130. FoS Probe Value of CB1, 6061-T6 aluminium, 5000N Force

4.9 FoS. (Factor of Safety) Findings

If any area of the rim displays a Factor of Safety (FoS) value of below 1, this indicates a likely failure under the applied load conditions. However, in all simulations conducted, the FoS values consistently exceeded 1, which confirms the structural integrity and durability of the rims.

The favourable result highlights the dependability of the design and the appropriateness of the material selections in guaranteeing that the rim can endure operating pressures without any breakdown.

Elektron 21: Yield: 170Mpa

Min FOS = 8.1 — 1000N of force
Min FOS = 1.6 — 5000N of force

AZ91: Yield: 160Mpa

Min FOS = 7.6 — 1000N of force
Min FOS = 1.5 — 5000N of force

6061-T6: Yield: 275Mpa

Min FOS = 13 — 1000N of force
Min FOS = 2.6 — 5000N of force

Discussion of the Findings:

After reviewing the data from FEA analysis and Factor of Safety testing, I can confidently state that none of the variations showed breakage or failures.

Upon examining the Factor of Safety results and stress analysis, I determined that the rim made from Elektron 21 possesses slightly better structural strength than that made from AZ91 magnesium alloy.

The outcome didn't surprise me, as even prior to these tests, it was apparent to me that Elektron 21, due to its superior physical properties, would be slightly more robust than AZ91.

The Factor of Safety data indicates that, across all tests, the minimum FoS value consistently exceeds 1. This ensures that the rim is capable of withstanding expected loads and forces without failure.

Consequently, Elektron 21, AZ91, and 6061-T6 materials are all suitable for Custorim's base rim.
However, my preference would be to use Elektron 21 for high-performance magnesium wheels and 6061-T6 Aluminum alloy for everyday cars.

5. Material Description

5.1 Magnesium Alloys

Elektron 21

Applications:

"Luxfer MEL Technologies has developed this lightweight, high-performance alloy for ***aerospace applications***. It is designed to provide ***superior mechanical properties*** and improved corrosion resistance together with good castability." 2. (Jamie, "Elektron® 21")

Density: **1,8g/cm3 or 1800kg/m3**

The density and other physical properties of Elektron 21 magnesium alloy is very similar to, even less than, that of AZ91 magnesium alloy, which means that my FEA (Finite Element Analysis) test results for AZ91 are also ensures the use of Elektron 21.

Heat Treatment:

Forged rims are given the following **T6 heat treatment** to obtain enhanced mechanical properties:

Solution treat for 8 hours at 520˚C (970˚F), Hot water quench using water at 60–80˚C (140–175˚F) or polymer quench, Age for 16 hours at 200˚C (400˚F), Air cool (Jamie, "Elektron® 21")

Minimum specification tensile properties:

Yield Strength: 145 MPa
Tensile strength: 248 MPa
Elongation: 2%

Low temperature mechanical properties:
(Typical mechanical properties at -35˚C)

Elongation: 7%
Ultimate Tensile Strength: 270 MPa

Physical Properties:

Modulus of elasticity: 44.8 x 103 MPa
Brinell hardness: 65–75

Ambient temperature mechanical properties:

Yield Strength: 170 MPa
Tensile Strength: 280MPa
Elongation: 5%

Surface Treatment:

Any of the common finishing, anodizing, and chromating processes are applicable, which means ***a large range of colour and finish options*** can be achieved to suit individual user preferences.

Castability:

Elektron 21 magnesium alloy provides **superior castability**, attributed to its minimal oxidation and **fine-grained microstructure**, which ensures detailed, robust, and pressure-tight castings.

Corrosion Resistance:

ASTM B117 salt spray test corrosion rate for base metal:
<1.14 mg/cm2/day
<90 mpy

Chemical Composition:

Zinc: 0.2–0.5% Neodymium: 2.6–3.1%z
Gadolinium: 1.0–1.7% Zirconium: Saturated
Magnesium: Balance

AZ91

Applications:

AZ91 is one of the most used magnesium alloys. It has been used especially in the automotive and aerospace industries where reducing weight is vital for improving both performance and fuel efficiency.

Applications include consumer electronics like laptop and smartphone cases, sports equipment, and vehicle components like instrument panels and seat frames.

Density: **1,81g/cm3 or 1810kg/m3**

Physical Properties:

Brinell hardness: 63

Modulus of elasticity: 45 GPa

Thermal conductivity (at 20degrees Celsius): 116 Wm-1K-1

Ambient temperature mechanical properties:

Yield Strength: ≈ 160 MPa

Tensile Strength: ≈ 240-250 MPa

Elongation: 3-7%

Chemical Composition:

Aluminum, Al	8.3-9.7
Manganese, Mn	0.15-0.50
Zinc, Zn	0.35-1
Silicon, Si	0.1

Copper, Cu	0.03
Iron, Fe	0.005
Nickel, Ni	0.002
Others, each max	0.02
Magnesium, Mg	Remainder

Fig. 131. Chemical Composition of AZ91 magnesium alloy, (AZoM, 2013)

Discussion

Given the unique properties of Elektron21 magnesium alloy, if I had the opportunity to bring the Custorim project to production, I would choose this material. Its robustness, which makes it suitable for aerospace applications, and its combination of strength and lightweight characteristics are pivotal in my decision.

These features significantly enhance the performance and functionality of the Custorim rims, making Elektron21 an ideal choice for this innovative rim system.

In SolidWorks, I selected magnesium alloy from the material library for testing, adjusting its properties to match those of the AZ91 and Elektron 21 magnesium alloys.

This adjustment in yield strength and tensile strength ensured that the Finite Element Analysis (FEA) provided accurate results. This methodological approach guarantees that the simulation closely replicates the real-world behavior of these materials under various stress conditions.

Property	Value	Units
Elastic Modulus	45000	N/mm^2
Poisson's Ratio	0.35	N/A
Shear Modulus	17000	N/mm^2
Mass Density	1700	kg/m^3
Tensile Strength		N/mm^2
Compressive Strength		N/mm^2
Yield Strength		N/mm^2
Thermal Expansion Coefficient	2.5e-05	/K
Thermal Conductivity	160	W/(m·K)
Specific Heat	1000	J/(kg·K)

5.2 Plastics

ABS

Applications:

ABS plastic is a material that is widely used in many different sectors due to its strength, durability, and adaptability and ease of manufacture.

Because of its properties, it is often utilized in vehicle components such as door handles, dashboard trim; laptops, cameras, televisions and others areas of design and engineering.

Density: **1020 kg/m3**

Physical Properties:

Modulus of elasticity: 1.6-2.4 GPa

Ambient temperature mechanical properties:

Yield Strength: ≈ 29.6 – 48 MPa

Tensile Strength: 29.8 - 43 MPa

Elongation: (at Break) = 10-50%
(at Yield) = 1.7-6%

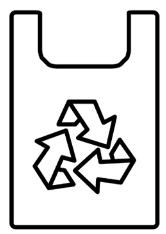
Melting Point:

Varies from 190°C to 260°C (374°F to 500°F), depending on the specific formulation.

Property	Value	Units
Elastic Modulus	2000	N/mm^2
Poisson's Ratio	0.394	N/A
Shear Modulus	318.9	N/mm^2
Mass Density	1020	kg/m^3
Tensile Strength	30	N/mm^2
Compressive Strength		N/mm^2
Yield Strength		N/mm^2
Thermal Expansion Coefficient		/K
Thermal Conductivity	0.2256	W/(m·K)
Specific Heat	1386	J/(kg·K)
Material Damping Ratio		N/A

Fig. 132. Material properties of ABS plastic on Solidworks

Recyclability and Lifecycle of ABS plastic:



ABS plastic is recyclable and biocompatible, designated by recycling number #9. It is fully recyclable, and combining recycled ABS with virgin material creates products while reducing costs for both consumers and manufacturers.

This approach enhances the sustainability and affordability of manufacturing processes.

By utilizing the recyclability of plastics, Custorim's spokes can be sustainably recycled at their end of use. These recycled materials can then be processed to create new Custorim Spokes, building an eco-friendly and sustainable cycle.

This method not only supports environmental sustainability but also promotes a business model that is circular.

5.3 Discolouring

"ABS plastic, widely used across various industries due to its impact resistance and versatility, has a notable limitation regarding its UV resistance. *Prolonged exposure to ultraviolet (UV) light can lead to the material's degradation*, causing it to become brittle and discoloured over time. This limits its applications outdoors or in environments where it would be exposed to direct sunlight without protective measures."
3. ("ABS Plastic: Definition, Composition, Properties and Uses")

to overcome…

There are 3 options;

1- ABS plastic can be blended with other polymers to have further increased levels of physical properties, such as PC, ASA.

2- During the injection moulding process, the Overmolding method can be used to cover ABS plastic with an outer shell made of a different material. An outer layer of a UV stabilized plastic can be utilized to block UV rays and avoid discoloration.

(This method not only increases the UV resistance of ABS items but also protects them from the sun without compromising their integrity or look. By combining the advantageous qualities of ABS with the UV-stabilized layer, this approach provides a complete defence against UV-related possible degradation.)

3- The ABS plastic can be covered with UV clear coating for having UV resistant outer layer.

Note: When black filament is being used, it has much more UV resistance than any other colour!

1. option - Mixing Plastics;

ASA/ABS

ASA/ABS is a material blend, combining Acrylonitrile Styrene Acrylate (ASA) and Acrylonitrile Butadiene Styrene (ABS).

Density: 1.04 g/cm³ Yield Strength: ***40-50 MPa.***

The properties of ASA/ABS blends are very similar, almost identical, to those of pure ABS material.

ASA/ABS blends aim to retain the mechanical properties of ABS while enhancing UV resistance and weatherability, courtesy of ASA.

The blend's properties can vary based on the ratio of ASA to ABS but generally offer improved resistance to weathering and UV light compared to pure ABS, without significantly compromising on density or yield strength. .

PC/ABS

ABS/PC is an abbreviated form used for acrylonitrile butadiene styrene/polycarbonate blend.
It is a thermoplastic alloy made up of polycarbonate and acrylonitrile butadiene styrene.
Both polymers are widely used on their own. They have very specific properties and drawbacks of their own.

Density: 1.05-1,20 g/cm³ Yield Strength: 40-100 MPa.

o Enhanced processability
o Good flow characteristics, strength, stiffness, and
o Good heat resistivity

This material may not be the best choice for additional spokes due to its lack of UV light protection.

2. option - Injection Moulding Solution;

Same UV light protection can be obtained by covering the outer shell of the ABS plastic by a UV stabilized layer such as ASA plastic at Injection Moulding stage to form a UV resistant ABS plastic, without being in need of costly and time-consuming applications such as blending materials.

The process efficiently integrates the advantages of both materials in a single part, enhancing UV resistance and appearance.

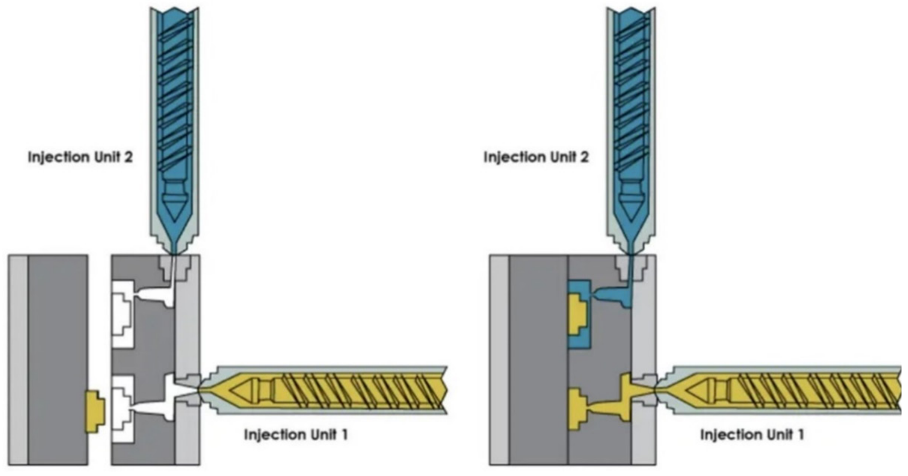


Fig. 133. Injection Moulding (www.linkedin.com, n.d.)

3. option - UV Resistant Coats;

UV Resistant Clear Coats:

UV-resistant clear coatings applied after injection molding or 3D printing offer protection comparable to blending ABS with ASA. This method is a cost-effective alternative to enhance UV resistance and weatherability of ABS components.

It would significantly improves the durability of Custorim Additional spokes, ensuring that the colors remain vibrant and the form remains same over time.

Applying a UV-resistant clear coating to Custorim's plastic additional spokes is significantly more cost-effective and straightforward compared to blending materials like ABS with ASA. This method eliminates the need for specialized raw materials and complex manufacturing processes. This streamlined approach not only saves on materials but also simplifies the manufacturing workflow.

Fig. 134. UV Clear Coat for ABS (SBL, n.d.)

6. DMF of Custorim Rim System

At the heart of the Custorim rim system lies a core design philosophy dedicated to versatility and user customization. This innovative approach has led to the creation of a base rim that is adaptable for manufacturing with two distinct materials - Elektron 21 magnesium alloy for performance-oriented applications and 6061-T6 aluminum alloy for everyday use.

The design features sleek, dual-divided spokes and an embedded attachment system, enabling the effortless addition of various ABS plastic spoke sets under three main series: Performance, Futuristic, and Classic. This not only elevates the aesthetic appeal and performance of vehicles but also unlocks unprecedented levels of customization in rim design.

Material Choices and Rationale

Elektron 21 Magnesium Alloy:

- Exceptionally lightweight due to its low density, significantly reducing unsprung mass for enhanced vehicle performance.
- Remarkably durable, benefiting from both the forging manufacturing method and a specialized heat treatment.
- Exhibits high corrosion resistance, great castability, and high heat strength, allowing for complex, enduring designs.
- Although manufacturing and purchase costs are higher compared to aluminum, its benefits for high-performance applications are unparalleled.

6061-T6 Aluminum Alloy:

- Boasts superior tensile properties achieved through heat treatment and forging, providing a robust alternative for daily-driven vehicles.
- Slightly denser and heavier than magnesium but offers a balance between performance and affordability.
- Its use in the industry for aluminum rims testifies to its reliability and cost-effectiveness, making it an attractive option for a broader audience.

Mixed Recycled ABS Plastic:

- Crafted from a blend of %80 virgin ABS filament and %20 recycled ABS, emphasizing the project's commitment to sustainability.
- Achieves a high-quality finish with layer line resolution up to 0.1mm, ensuring smooth layer lines for a refined appearance.

Catering to Individual Preferences

The Custorim system offers a variety of finishes tailored to customer preferences, from brushed metallic and glossy coatings on metal rims to textured or soft-touch finishes on ABS plastic additional spokes.

Utilizing advanced techniques such as CNC machining and tumbling, these diverse finishes allow customers to extensively personalize their rims according to their taste and vehicle aesthetics.

6.2 Manufacturing Processes of Custorim Base Rim

Manufacturing Processes of Custorim Products

1. Material Selection: Elektron 21 magnesium alloy for performance applications. 6061-T6 aluminum alloy for daily drive cars.
2. Forging Process: The selected material is forged to shape, enhancing its mechanical properties and durability.
3. Trimming Process: Excess material from the forging process is trimmed to refine the shape and prepare for further machining.
4. Heat Treatment: The rim undergoes T6 heat treatment to further improve its tensile strength and resistance.
5. CNC Machining: Precision machining creates sleek, dual-divided spokes, bolt holes, and the positive side of the slide attachment mechanism on the base rim.
6. Finishing: A variety of finishing options including powder coating, brushed metallic, and glossy finishes are applied based on user preferences.

Fig. 135. CSC1 assebled on CB1

Fig. 136. Custorim Additional Spokes Renders

6.3 Manufacturing Processes of Custorim Additional Spokes

1. Material Preparation:
A blend of 80% virgin ABS material and 20% recycled ABS is prepared, ensuring both sustainability and material quality. Coloring options are integrated into this blend for inherent coloration or applied via painting before the finishing stage.

2. 3D Printing (FDM):
Additional spokes are produced using Fused Deposition Modeling (FDM), allowing for intricate designs and customization. The layer resolution may vary to achieve the desired finish quality.

3. Automatic Support Removal (Submersed Vortex Cavitation (SVC)):
In 3D printing, support structures are used to uphold the design integrity during the print process. Removing these supports manually is time-consuming and requires accuracy to avoid damaging the printed parts. By systematically removing supports without the need for human assistance, automatic support removal machines make this process simpler. Machine that can be used for this stage; PostProcess™ DECI Duo

4. Tumbling and Supplementary Finishing:
Post-printing, the spokes undergo tumbling and other finishing processes to enhance surface quality and aesthetic appeal.

5. Color and Finish Customization:
Extensive color and finish options, including soft-touch and glossy finishes are made available to cater to diverse user preferences.

7. Unique Selling Point of the Custorim Rim System

The Custorim rim system represents a paradigm shift in automotive customization, offering an unparalleled blend of performance, aesthetics, and personalization. Its unique selling point lies in the innovative integration of advanced materials with modular design, allowing users to effortlessly customize their vehicle rims to suit their individual style and performance needs.

The use of high-quality Elektron 21 magnesium and 6061-T6 aluminum alloys ensures that the base rims are not only lightweight and durable but also cater to a wide range of automotive applications, from high-performance to everyday driving.

Moreover, the Custorim system stands out for its sustainable approach, utilizing recycled ABS plastic in the production of additional spokes, which can be easily attached to the base rim thanks to the modular attachment system.

This system not only promotes environmental sustainability by preventing users from buying new set of rims each time, also offering users the flexibility to update their rims' appearance and functionality over time.

With its comprehensive online catalog and continuous engagement initiatives like the "Starter Pack 3+1" and the "Additional Spoke Return Program," Custorim offers a distinct value proposition. This approach not only enhances vehicle aesthetics and performance but also embodies modern values of sustainability and personalized consumer experiences,

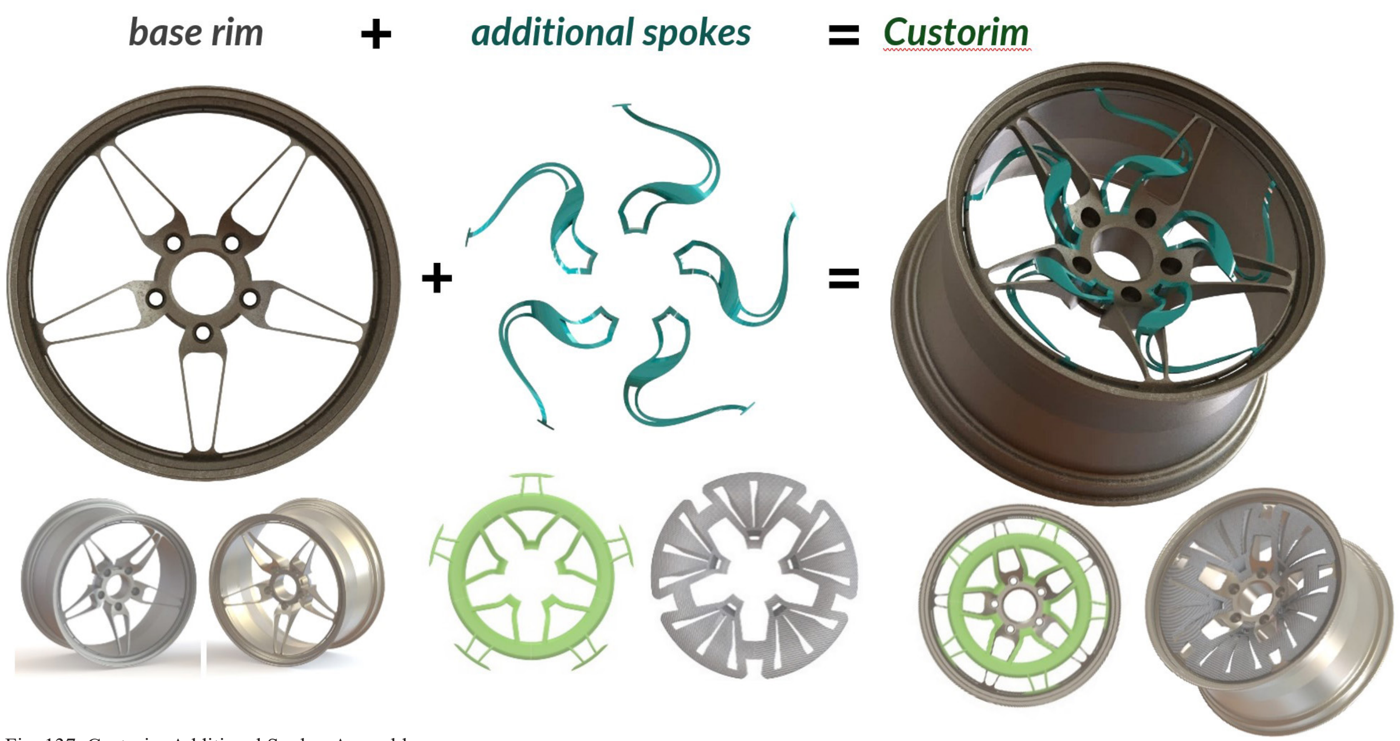


Fig. 137. Custorim Additional Spokes Assembly

7.2 Additional Spoke Design Capabilities

Custorim's foundational rim design is engineered for having full performance independently, negating the necessity for additional spokes assembly. This innovative method ensures that additional spokes are free from structural stress, which allows a broader exploration of designs, including curvilinear, sharp edges, three-dimensional shapes, and asymmetric forms.

This strategic design adaptation allows Custorim to present an extensive portfolio of unique and visually appealing spoke designs, aligning with diverse consumer preferences while maintaining structural integrity and security.

Cost-efficiency:

Custorim's rim technology is notable for its economical nature. The ability to swap out additional spokes on an extremely durable and lightweight rim saves customers of the expense of buying whole new rim sets in order to further customize their wheels, which is a crucial component of a vehicle's overall appearance.

This innovative solution aligns with both economic and environmental benefits by reducing waste and saving money over time and becomes a much better alternative to monolithic, aftermarket wheels. This technology offers a cost-effective option for anyone looking to add flair, and diversity to their car's look without having to pay a lot of money for several rim purchases.

Certificate No. FM12677

Fig. 138. Elektron 21 Certifications (DATASHEET • 455 † Elektron ® 21, n.d.)

Performance:

Elektron 21 Magnesium – Aerospace Technology:

One of the primary marketing highlights for Custorim is its foundation on the "Elektron 21" magnesium alloy for base rims, a material developed by Luxfer MEL Technologies.

This decision points out Custorim's commitment to quality and performance, using Elektron 21's renowned properties.

This material is developed specifically for aerospace technologies and motorsports, offering superior tensile strength, extreme use temperatures(+200°Celcius), enhanced durability, and exceptional lightweight properties than any other magnesium alloy.

Weight Reduction:

Custorim utilizes "Elektron 21" alloy for its rims, crafting them to be slim yet robust, and light yet strong. Elektron 21 alloy boasts a density of 1.8 g/cm³, closely mirroring that of AZ91, the most prevalently used magnesium alloy.

The magnesium base rim of Custorim, measuring 17 inches, weighs 4.7 kg. This is lighter compared to the 17-inch magnesium wheels offered by competitors. Also, the aluminium CB1, weights 7.5kg, makes it roughly %20 ligther compared to the standart OEM Cast wheels of user's vehicles.

±%25 less unsprung mass compared to its competitors!

±%20 less unsprung mass compared to OEM aluminum wheels!

This weight reduction is due slimmer design allowed by this material's extreme tensile properties. Such a reduction in weight grants users improved handling, pace and shorter braking distances, thereby enhancing the overall driving experience.

Performance Series Spokes:

The Performance Series additional spokes exemplify how specific customization options can significantly impact the vehicle's dynamics and overall performance. Engineered to enhance the rim's performance by lowering drag and improving brake cooling, this additional spoke series appeal to users seeking to improve their vehicle's performance.

The tangible benefits provided by the Performance Series encourage users to explore new additional spoke options, fostering a continuous engagement with the Custorim system.

Sustainability:

ABS Recycle Additional Spokes (eco-friendly):

Custorim's attention to sustainability can be seen by its creative ABS recycling system for its additional spokes. Custorim establishes a cycle where spokes get appropriately recycled after usage by taking advantage of ABS plastic's 100% recyclability.

This method not only promotes environmentally friendly manufacturing yet also facilitates the utilization of recycled ABS when mixed with virgin materials, in order to generate a product that is environmentally friendly and affordable.

Thus, Custorim establishes a precedent in creating new, environmentally friendly rim system, showing a dedication to environmental responsibility and circular economy principles.

7.3 User Engagement with the Custom Rim's Modular Attachment System

The Custorim rim system implements a customer-orientated method for customisation, enabling vehicle owners to effortlessly personalise and enhance properties of their rims by choosing from a range of extra spoke sets that are specifically intended to cater to diverse aesthetic and functional preferences.

Assembly Steps Of Custorim Additional Spokes (SC) on to CB1:

Step 1: Choosing the Preferred Additional Set of Spokes

The user journey begins with users selecting from three series of additional spoke sets: the Performance Series (CSP), aimed at enhancing vehicle performance, functionality and efficiency; the Futuristic Series (CSF), featuring unique and forward-thinking designs; and the Classic Series (CSC), which offers timeless, sometimes vintage-inspired aesthetics.

This option enables customers to select rims that align with their individual style or performance requirements.

Step 2: Assembling the Extra Spokes

Assembly begins by placing the outer slot of the additional spoke into the cavities located around the circumference of the rim. This essential procedure guarantees that the extra spokes are firmly attached, thereby preventing unintended detachment caused by external factors like wind or water.

Step 3: Finalizing the Attachment

The second component of the attachment mechanism has a crucial function in the assembling process.
The additional spoke's central piece is cleverly connected to the rim's body by being strategically placed around the perimeter of the rim's centre. This arrangement enables the connection of each additional spoke at two points.

The process successfully connects the additional spokes to the structure of the rim, creating a smooth integration and a finished look.

Step 4: Ensuring Uniform Distribution

In order to maintain weight balance and uniformity, the operation of attaching five extra spokes per rim is repeated, following the chosen sequence for each wheel. This methodical technique guarantees that the rims retain equilibrium, thereby avoiding any potential weight disparities that may have a negative impact on the vehicle's handling and performance.

The Custorim project revolutionises the rim customisation experience by combining the innovative engineering of the modular attachment system with the customisable possibilities of extra spoke sets.

This pioneering approach not only points out the dedication to innovative design and user engagement but also sets a new benchmark for combining functionality and aesthetic variety in the automotive rim market.

7.4 User Interaction and Customization Process in the Custorim Rim System

How users interact with the product and customize it to their needs?

The Custorim rim system introduces an innovative approach to automotive customization, seamlessly blending user-centric design with a broad spectrum of personalization options.

Customization Journey of CB1-Base Rim:

1. Material Selection: Users initiate the customization process by selecting the base rim material. They can choose Elektron 21 magnesium for superior performance or 6061-T6 aluminum for everyday reliability.
2. Size Specification: The next step involves selecting the appropriate rim size and width to match the vehicle's specifications.
3. Color and Finish Customization: Users then select their preferred colour from a variety of options. The specific finish, achieved through processes such as tumbling and CNC machining, is also chosen to complete the aesthetic customization of the base rim.

Customization Journey of Custorim Addditional Spokes (SC):

1. Design Selection: Customers begin by selecting their preferred Custorim additional spoke designs from the Custorim 23/24 product line avaiable on Custorim Product Catalogue and website.
2. Size Correlation: It is essential to ensure that the chosen additional spokes correlate in size with the Custorim Base rim which is already seleceted by the user prior to this stage.
3. Color and Finish Options: Users can choose or specify their desired colors and finishes for the additional spokes, enhancing the personalized aspect of their vehicle.
4. Order and Assembly: Finally, customers place their orders through www.custorim.com, which showcases all available design options, material and finish choices, and provides detailed instructions on the attachment process. The website, currently conceptual and under development, will eventually support online customization and purchasing.

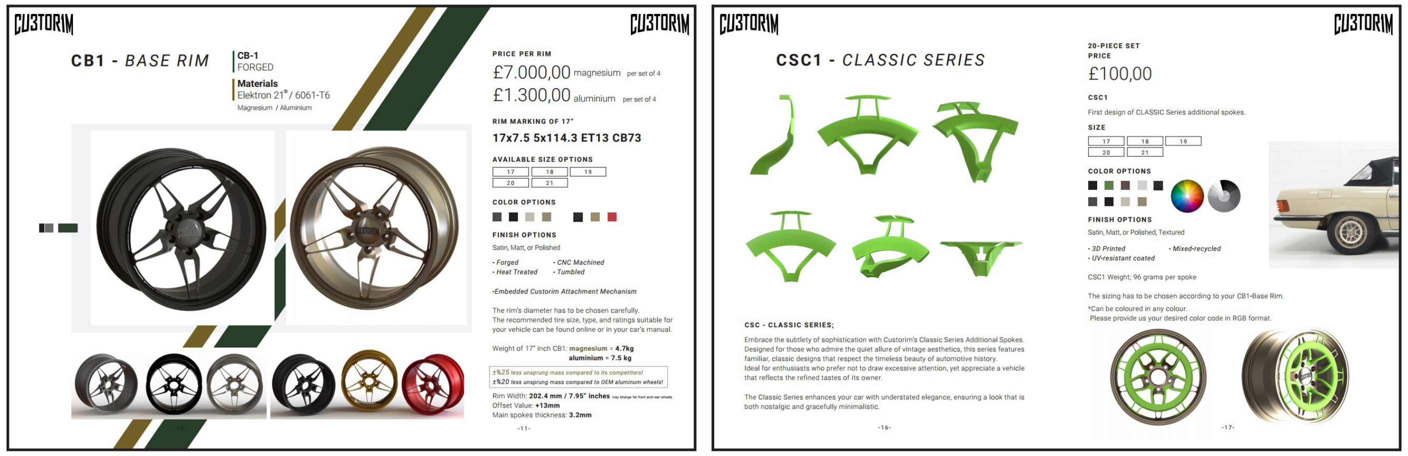


Fig. 139. Custorim Catalogue Pages of CB1 and CSC1

8. Custorim Product Range

8.1 Custorim Base Rim

CB1

Comes with two material options;

Magnesium alloy - Elektron 21

Aluminium Alloy - 6061-(T6)

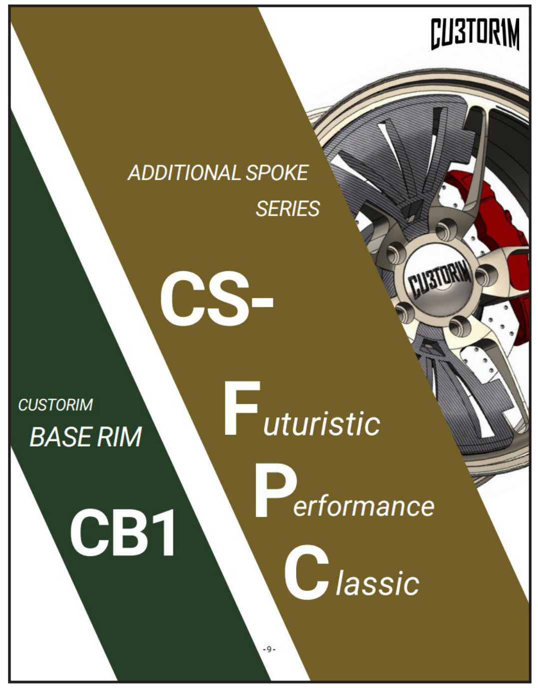


Fig. 140. Custorim Catalogue Page

8.2 Custorim Additional Spoke Series

FUTURIST (CSF) *CLASSIC (CSC)* *PERFORMANCE (CSP)*

Custorim offers a distinctive selection of additional spoke designs and various finish and colour options within its catalogue.

Futuristic Series

Highlighted from the broader collection, the "Futurist Series" spokes, showcases a standout design featuring asymmetric patterns, unique geometries and curvaceous features, aimed at enthusiasts looking for modern, innovative designs.

Classic Series

From the "Classic Series", we spotlight a design that champions familiar yet bold circular shapes, perfectly suited for those who value timeless design geometries and simplicity.

Performance Series

Lastly, the "Performance Series" presents an aerodynamically inspired option, meticulously engineered to reduce drag coefficient, and enhance brake cooling.

8.3 Pricing

Custorim Base Rim

CB1 – Magnesium:	**£7000**	(set of 4)
CB1 – Aluminium:	**£1300**	(set of 4)

Custorim Additional Spokes

CSP (Performance Series):	**£125**	(set of 20)(for all 4 wheels)
CSC (Classic Series):	**£100**	(set of 20)(for all 4 wheels)
CSF (Future Series):	**£100**	(set of 20)(for all 4 wheels)

Custorim Additional Spokes

Custorim Centre Caps:	**£30**	(each)

8.4 Offers

Custorim acknowledges the dynamic nature of consumer preferences and the desire for periodic customization updates. To accommodate this, several flexible offers are provided, allowing users to adapt or upgrade their rim customizations over time.

Starter Package 3+1:

To encourage exploration and diversity in customization, Custorim offers a "Starter Pack 3+1" deal, granting a 15% discount when users purchase three different additional spokes sets. This initiative motivates users to experiment with various designs and functionalities, enhancing their vehicle's aesthetics and performance.

Additional Spoke Return Program:

Recognizing the importance of sustainability, Custorim has instituted an "Additional Spoke Return Program." This program invites users to return their damaged, used, or no longer desired additional spokes and offer them 20% discount on their new additional spoke set purchase.

These returned spokes are then recycled, with the ABS material being blended with virgin ABS for the 3D printing of new spokes.

This circular approach not only supports environmental sustainability but also offers a cost-effective way for users to update their customization choices.

8.5 Custorim Branding (Visual Identity)

Logo:

Fig. 141. Custorim Logo Colour Variations

Instead of the letters S and I, the numbers 3 and 1 are used in the logo to represent the "Custorim Starter Pack3+1" set, which comprises of 1 base rim plus 3 different sets of extra spokes.

This creative design choice reflects the brand's unique offering and customization options directly within its visual identity.

Font:

Roboto

- Using a consistent font across all brand materials, including presentations, presentation boards, and product catalogues, is essential for maintaining a cohesive brand identity.
- This consistent visual style helps to strengthen brand recognition and ensures that all communications are immediately identifiable as part of the brand.

Fig. 142. Custorim Font, Roboto

Colour Palette:

Primary Colour

Secondary Colour

Fig. 142. Custorim Colour Palette (Coolors.co. (n.d.))

9. Final Renders

9.1 Custorim 23/24 Product Catalogue

Custorim 23/24 Product Catalogue, showing the system, product offers, customization options, pricing and some example applications images on actual cars.

Custorim Product Catalogue can be further investigated by scanning the QR code below!

10. Conclusion

The Custorim project represents a groundbreaking approach in the automotive customization sector, successfully demonstrating the viability of a modular rim system that marries aesthetic adaptability with enhanced functional performance. Throughout this project, I have tackled prevalent market gaps, manufacturing problems by introducing a system that not only meets but anticipates the diverse preferences and performance expectations of car owners while maintaining engineering standarts.

Project Achievements:

Innovative Design: I developed the Custorim interchangeable rim system, enabling dynamic customization through the addition of lightweight spokes that enhance performance without substantial weight increase, directly addressing the need for better handling and reduced unsprung mass in performance vehicles.

Material Science Application: Utilized advanced materials, specifically Elektron 21® Magnesium and 6061-T6 Aluminum, chosen for their optimal balance of weight, strength, and durability. This choice was substantiated by rigorous material property comparisons and suitability for high-performance and daily use scenarios.

Sustainable Manufacturing: Integrated eco-friendly practices by using recycled ABS plastic for the production of additional spokes, contributing to sustainability in automotive parts manufacturing.

Extensive FEA Testing: Undertook comprehensive Finite Element Analysis to validate the structural integrity and durability of the rims under real-world driving conditions. This testing ensured that the rims could withstand varied stresses and impacts, affirming their safety and reliability.

Realization Through Prototyping: Advanced from concept to functional prototypes, employing state-of-the-art manufacturing processes such as forging and CNC machining. This stage was crucial for refining the design and ensuring manufacturability.

Detailed Documentation: Produced the Custorim 23/24 Product Catalogue, which showcases the customization flexibility and the array of options available, further proving the project's readiness for market introduction.

Strategic Engineering and Marketing Integration: Meticulously planned and executed a branding and marketing strategy to position Custorim effectively within the competitive landscape of the aftermarket wheel aftermarket.

This project has laid a robust foundation for future development and potential market entry. It underscores my ability to conduct detailed engineering analysis and development, showcasing my readiness to contribute significantly to the field of product design engineering.

Future enhancements will focus on expanding the product range, improving durability and safety through ongoing engineering efforts, and increasing the adoption of sustainable practices. This endeavor has not only solidified my engineering capabilities but also provided deep insights into transitioning innovative designs into viable commercial offerings.

I would like to thank to my tutors, whose guidance and expertise have been instrumental in shaping this project. Their invaluable feedback and relentless support have profoundly impacted my approach and execution throughout this project.

Special appreciation goes to the workshop and 3D printing technicians at Brunel University. Their dedication and assistance in the realization of the prototypes were crucial to the practical aspects of my project.

Additionally, I am grateful to the Technology Placement Office (TPO) for facilitating my placement year, which significantly enriched my industry knowledge and practical experience. The insights gained during this period were vital in identifying the real-world challenges and opportunities that Custorim aims to address.

References

Figure References;

Fig. 1. Conventional Cast Aluminium Design and Manufacturing Stages (Level3 - CMS - Placement Report)

Fig. 2. Sparco 16 inch wheel cover Lazio (Amazon.uk)
Amazon. (n.d.). Available at: https://www.amazon.co.uk/Sparco-SPC1691BKGR-wheel-covers-16-inch/dp/B01NCMZUN3/ref=sr_1_2?crid=37WM7EU0MVMBC&dib=eyJ2IjoiMSJ9.vXiVmdAeGsl3b8Ay-1Fn-gSFBIWCvaL5BlzctOAvVtuSHSK_yI1VNsrTxHwQMIn6QLPNMY6xK5gjCrYQJfxEeKedkAsn-ZrNLPHWJZPRAiLfyIXO4CNu6D-x1jLdXJQyMsdowXXQsUsjGsZ4HYU6SUrNNWJ5Zpf378LT-vNfNoPBcTL0qUTHTOZurEecA262wnKJPmDbVWWRXgEj0zFLzKTaiS46lyb6j1Ad-JJAtQCHs4.hVKxNzv6XRzm8DZnZrPCh5lP_5YbRbKMtvU-MbAzUE4&dib_tag=se&keywords=sparco%2B16%2B-wheel%2Bcover&qid=1714651572&sprefix=sparco%2B16%2Bwheel%2Bcov%2Caps%2C157&s-r=8-2&th=1.

Fig. 3. Sparco 16 inch wheel cover Roma (Amazon.uk)
Amazon. (n.d.). Available at: https://www.amazon.co.uk/SPARCO-SPC1696GRBK-Wheel-Covers-16-inch/dp/B07NJJ26ZB/ref=sr_1_3?crid=3HFW1HWY1MBG7&dib=eyJ2IjoiMSJ9.JMxNQQxe4jzIpks-fRgDWCvJRcuTZ8_QfMFkF_H2W2aFuWD9wc_VNnHH-6lK8y3GN6_A-NQzSYxDoidHAb0lCVh-31GTR317P7JDUio0Nuv-HnpdtyGrE0V8DuZSK5WCihAKQPJu7JCfIcsLRKKR-klYTKO5cQPaY-dtdCCQXerrrBI2bf3cbIX77F6czr_z83jt2RpDJ-8dX98wOsOX_cqjm5pQkKHaQtg_D_il6Nn61A.MZ7SR4xB8DEQwRKLbuGOZZdssvfFXD0e3ue6GilVeu0&dib_tag=se&keywords=sparco+16+wheel+-cover+roma&qid=1714651909&sprefix=sparco+16+wheel+cover+rom%2Caps%2C169&sr=8-3.

Fig. 4. Romac Radium Gloss Black 19inch (www.wheelbasealloys.com, n.d.)
www.wheelbasealloys.com. (n.d.). 19" Romac Radium Gloss Black Alloy Wheels. [online] Available at: https://www.wheelbasealloys.com/alloy-wheels/romac/radium/gloss-black/19-inch?currency=GBP&utm_source=google&utm_medium=cpc&utm_campaign=shopping&gad_source=1&gclid=Cj0KCQjwlN6wBhC-cARIsAKZvD5hMaTAtV-9u5Y_jTh1DjzCoSMKBoR15qbNWN49BrGCE73QtgNBpk54aAoMOEALw_wcB [Accessed 2 May 2024].

Fig. 5. CVR1 Brushed Bronze (www.wheelbasealloys.com, n.d.)
www.wheelbasealloys.com. (n.d.). 19" Concaver CVR1 Brushed Bronze Alloy Wheels. [online] Available at: https://www.wheelbasealloys.com/alloy-wheels/concaver/cvr1/brushed-bronze/19-inch [Accessed 2 May 2024].

Fig. 6. OZ Rally Racing Graphite 19inch (www.wheelbasealloys.com, n.d.)
www.wheelbasealloys.com. (n.d.). 19" OZ Racing Rally Racing Graphite Alloy Wheels. [online] Available at: https://www.wheelbasealloys.com/alloy-wheels/oz-racing/rally-racing/graphite/19-inch [Accessed 2 May 2024].

Fig. 7. IPE MFR-02 Magnesium Aftermarket Wheels (String Theory Garage, n.d.)
String Theory Garage. (n.d.). IPE MFR-02 Magnesium Wheels. [online] Available at: https://stringtheorygarage.com/products/mfr-02-magnesium-wheels?variant=45537110589717 [Accessed 2 May 2024].

Fig. 8. BBS RE-MTSP (BBS RE-MTSP - 19, 2017)
BBS RE-MTSP - 19 (2017). BBS RE-MTSP - 19. [online] System Motorsports. Available at: https://www.systemmotorsports.com/products/bbs-re-mtsp-19-20 [Accessed 2 May 2024].

Fig. 9. Rotiform AeroDisc 19inch (eBay, n.d.)
eBay. (n.d.). Available at: https://www.ebay.co.uk/itm/364335729973?chn=ps&_ul=GB&norover=1&m-kevt=1&mkrid=710-134428-41853-0&mkcid=2&mkscid=101&itemid=364335729973&target-id=1814673648942&device=c&mktype=pla&googleloc=9046083&poi=&campaignid=19089547614&mk-groupid=142438599285&rlsatarget=pla-1814673648942&abcId=9303859&merchantid=137585916&gad_source=1&gclid=Cj0KCQjwir2xBhC_ARIsAMTXk86SMsZtI5bcKnJbXOD_pRXYt2PiND1AqTwef5iNZ-jnYgK50Yiwg5-AaAjBxEALw_wcB.

Fig. 10. Rotiform AeroDisc Sticker Variations (artstation, n.d.)
artstation. (n.d.). Available at: https://www.artstation.com/marketplace/p/Jw8G7/rotiform-rse-aerodisc.

Fig. 11. Rotiform AeroDisc in use (Pinterest, n.d.)
Pinterest. (n.d.). Rotiform Aero Disc | Rims for cars, Cool car accessories, Concept car design. [online] Available at: https://www.pinterest.de/pin/395613148530226506/ [Accessed 2 May 2024].

Fig. 12. HRE (Hrewheels.com, 2019)
Hrewheels.com. (2019). HRE Performance Wheels. [online] Available at: https://www.hrewheels.com/wheels/concepts/hre3d.

Fig. 13. Ferrari Roma OEM Wheels (Modulare, n.d.)
Modulare (n.d.). SEMA 2022 + Ferrari Friday | 2022 Ferrari Roma | Introducing the Modulare B45 | Modulare Wheels. [online] Available at: https://modularewheels.com/sema-2022-ferrari-friday-2022-ferrari-roma-introducing-the-modulare-b45/ [Accessed 2 May 2024].

Fig. 14. Ferrari Roma OEM Wheels (360WHEELS, n.d.)
360WHEELS. (n.d.). 20. [online] Available at: https://360wheels.com.hk/products/20-ferrari-roma-forged-wheels [Accessed 2 May 2024].

Fig. 50. 18-inch magnesium wheels by MB Design (www.tunershop.shop, n.d.)
www.tunershop.shop. (n.d.). MB Design Wheel MF1 7,5x18 ET45 5x108 18 Inch black matt. [online] Available at: https://www.tunershop.shop/mb-design-wheel-mf1-7-5x18-et45-5x108-18-inch-black-matt-mf17518455ez-bp1.html [Accessed 3 May 2024].

Fig. 56. Snow Chain (Snowchainstore, n.d.)
Snowchainstore. (n.d.). Spikes Spider Easy Sport 3. [online] Available at: https://www.snowchainstore.co.uk/spikes-spider-easy-sport-3 [Accessed 3 May 2024].

Fig. 57. Chameleon Snow Chain (eBay, n.d.)
eBay. (n.d.). Available at: https://www.ebay.co.uk/itm/266277574384?_trkparms=amclksrc%3DIT-M%26aid%3D1110006%26algo%3DHOMESPLICE.SIM%26ao%3D1%26asc%3D262497%26meid%3Dc-722cf9ece254b93ad02578e072fa057%26pid%3D101875%26rk%3D2%26rkt%3D4%26s-d%3D156138404467%26itm%3D266277574384%26pmt%3D1%26noa%3D0%26pg%3D4429486%26al-gv%3DSimplAMLv11WebTrimmedV3MskuWithLambda85KnnRecallV1V2V4ItemNrtInQueryAndCas-siniVisualRankerAndBertRecallWithVMEV3CPCAutoWithCassiniEmbRecallManual&_trksid=p4429486.c101875.m1851&itmprp=cksum%3A266277574384c722cf9ece254b93ad02578e072fa057%7Cenc%3AAQAJAAABcLSVkHmTL63bebovD9RfpraPWbY9f4anjbziTIaEIOVXg2DWhVLks3Lfqff9vxxfjIh4XEXusIe-hlT2iEH8%252BCxXNySMxlDIQJ3g86%252Bx3AAIAq9gznqdGSR72ksP41kjzPN1reUbVsJuld0S4i4qX-lQfTmkMeIJTCXTM8mLpr7ju2fMvruDu87ZX%252B4bShOvD%252B4seBSulbJQ9J3mF03NtQlMznY-k5oHMg8rvlJC64EBCX3TWVTRXmirVlaYrclKWCqBrg7vlSxHNYYqeUvNjAp8Aq4QgJ2Ms8pg6ENn-LebTCDLp1IC9mfMyDE8KWW%252FzivJFA7QBIlzHRSycd0%252BtA0BGOLyeji7AvU4IyszOp29L-rFrfUrjvCdjKJcp%252BhIV0ukhlvztsqRu1bOMwGr9BZuW96XflnLQXj%252FlG4f3QkjRuYomKCaD-jY3Cfym2%252BqwN6YHKbQQ6Ii8L2VVAe1F8BA39q3dUfLbo9wjFENmFzbUPq4%252FR%7Cam-pid%3APL_CLK%7Cclp%3A4429486&itmmeta=01HTQ8V3DCK01EMZBV9A28XWGH.

Fig. 58. Spikes Spider Sport M. Snow Chain (Snowchainstore, 2024)
Snowchainstore. (2024). Spikes Spider Sport M. [online] Available at: https://www.snowchainstore.co.uk/spikes-spider-sport-m [Accessed 3 May 2024].

Fig. 65. Zanini, AERO & AERODINÁMICA ADAPTATIVA (Zanini , n.d.)
Zanini . (n.d.). Available at: https://zanini.com/en/wheel-trim-2/.

Fig. 66. Tesla Turbine Wheel Concept (luxendary, 2017)
luxendary (2017). Will these turbine wheels make it to production? I hope they will... [online] Available at: https://www.reddit.com/r/teslamotors/comments/69v3sw/will_these_turbine_wheels_make_it_to_production_i/ [Accessed 3 May 2024].

Fig. 67. Jet engine (Arnot, 2019)
Arnot, M. (2019). 'The Most Fascinating Machines': How Jet Engines Work. [online] THE POINTS GUY. Available at: https://thepointsguy.com/news/how-jet-engines-work/.

Fig. 74. DS X E-Tense Concept Car (www.dsautomobiles.co.uk, n.d.)
www.dsautomobiles.co.uk. (n.d.). DS X E-TENSE : electric and autonomous concept car. [online] Available at: https://www.dsautomobiles.co.uk/ds-experience/concept-cars/ds-x-e-tense.html.

Fig. 75. DS X E-Tense Concept Car, side view (www.dsautomobiles.co.uk, n.d.)
www.dsautomobiles.co.uk. (n.d.). DS X E-TENSE : electric and autonomous concept car. [online] Available at: https://www.dsautomobiles.co.uk/ds-experience/concept-cars/ds-x-e-tense.html.

Fig. 116. Stress-strain curve with yield-strength (Team Xometry, 2023)
Team Xometry (2023). Yield Strength: Definition, Importance, Graphs, and How to Calculate. [online] www.xometry.com. Available at: https://www.xometry.com/resources/3d-printing/yield-strength/.

Fig. 131. Chemical Composition of AZ91 magnesium alloy (AZoM, 2013)
AZoM (2013). Magnesium AZ91D Cast Alloy. [online] AZoM.com. Available at: https://www.azom.com/article.aspx?ArticleID=9219.

Fig. 133. Injection Moulding (www.linkedin.com, n.d.)
www.linkedin.com. (n.d.). ABS Plastic Injection Moulding: The Ultimate Guide. [online] Available at: https://www.linkedin.com/pulse/abs-plastic-injection-moulding-ultimate-guide-daoben-machinery/.

Fig. 134. UV Clear Coat for ABS (SBL, n.d.)
SBL. (n.d.). Best. [online] Available at: https://www.sblcoatings.com/products-details/9007-05-uv-clear-matt-for-abs [Accessed 6 May 2024].

Fig. 138. Elektron 21 Certifications (DATASHEET • 455 † Elektron ® 21, n.d.)
DATASHEET • 455 † Elektron ® 21. (n.d.). Available at: https://www.luxfermeltechnologies.com/wp-content/uploads/2021/09/Luxfer-MEL-Technologies-Elektron-21.pdf.

References;

https://www.team-bhp.com/forum/tyre-alloy-wheel-section/227878-understanding-alloy-wheels-width-pcd-offset-etc.html 1

https://www.xometry.com/resources/3d-printing/yield-strength/

ŞIK1□Aydın, et al. Taşıt Jantlarının Yapısal Analiz İle Yorulma Dayanımının Belirlenmesi. 2015.
mbDESIGN. "MB MF1 7,5x18" 5x100 Et44.0 67.1 5AZ Black Shiny." MbDESIGN Wheels Onlineshop, mbdesign.shop/en/mb-magenesium-felge-mf1-7-5x18-et44-5x100-5az-schwarz-glaenzend. Accessed 11 Apr. 2024.
Jamie. "Elektron® 21." Luxfer MEL Technologies, www.luxfermeltechnologies.com/products/elektron-21/.

DATASHEET • 455 † Elektron ® 21. https://www.luxfermeltechnologies.com/wp-content/uploads/2021/09/Luxfer-MEL-Technologies-Elektron-21.pdf

"Magnesium Elektron 21 Alloy (UNS M12310)." AZoM.com, 18 June 2013, www.azom.com/article.aspx?ArticleID=9278.

AZoM. "Magnesium AZ91D Cast Alloy." AZoM.com, 14 June 2013, www.azom.com/article.aspx?ArticleID=9219.

https://www.protolabs.com/materials/abs/
Omnexus. "Acrylonitrile Butadiene Styrene (ABS Plastic): Uses, Properties & Structure." Omnexus, 2019, omnexus.specialchem.com/selection-guide/acrylonitrile-butadiene-styrene-abs-plastic.

"Acrylonitrile Butadiene Styrene - ABS High Impact UV Stabilised." AZoM, 4 May 2001, www.azom.com/article.aspx?ArticleID=361. Accessed 11 Apr. 2024.

"ABS Plastic Injection Moulding: The Ultimate Guide." Www.linkedin.com, www.linkedin.com/pulse/abs-plastic-injection-moulding-ultimate-guide-daoben-machinery/.

"ABS Plastic: Definition, Composition, Properties and Uses." Ruitai Mould, www.rtprototype.com/what-is-abs-plastic/.

"Overmolding and Insert Molding: From Prototyping to Production." Formlabs, formlabs.com/uk/blog/overmolding-insert-molding/.

Coolors.co. (n.d.). Coolors.co. [online] Available at: https://coolors.co/16501a-ffffff-7d6612-000000-babfbb.

www.tirebuyer.com. (n.d.). Impact of Wheel Weight on Your Vehicle | TireBuyer.com. [online] Available at: https://www.tirebuyer.com/education/impact-of-wheel-weight.

Quote References;

1. (KONIG, 2010)
KONIG (2010). What is PCD. [online] Konig Wheels. Available at: https://konigwheels.com/wheel-info-tech/what-is-pcd/#:~:text=What%20does%20PCD%20mean%3F [Accessed 6 May 2024].

2. (Jamie, "Elektron® 21")
Jamie. "Elektron® 21." Luxfer MEL Technologies, www.luxfermeltechnologies.com/products/elektron-21/.

3. ("ABS Plastic: Definition, Composition, Properties and Uses")
"ABS Plastic: Definition, Composition, Properties and Uses." Ruitai Mould, www.rtprototype.com/what-is-abs-plastic/.

Major Project Report

Custorim Interchangeable Rim System

Bora Sen
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