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Design and Optimization of a Lightweight Automotive Chassis for Sustainable Mobility

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ABSTRACT – *This paper presents the design and development of a lightweight Formula Student chassis aimed at improving performance, sustainability, and energy efficiency in a Formula Student race car. The chassis was engineered to be 20–30% lighter than the previous design without sacrificing structural strength. Advanced design techniques, including 3D Computer-Aided Design (CAD) modelling and Finite Element Analysis (FEA) simulation, were employed to optimize the chassis geometry and validate its structural integrity under load conditions. High- strength lightweight steel tubing (hollow "black pipe" and Schedule 40 pipe) was selected to reduce weight while meeting safety requirements. Simulation results indicate that the new design can withstand expected forces with adequate safety margins, and the weight reduction contributes to improved acceleration, handling, and energy efficiency of the vehicle. The prototype SLChassis was integrated into a 135cc Formula Student Malaysia 2025 race car, which achieved second place in the endurance race event and 4th in the design category. These results demonstrate the effectiveness of the lightweight chassis in enhancing vehicle performance. The innovations from this project underscore the importance of lightweight design and material optimization in sustainable mobility. This paper details the design methodology, simulation validation, and performance outcomes of the chassis, highlighting its potential for broader application in energy-efficient and sustainable vehicle engineering.*

KEYWORDS: Automotive chassis, Computer-Aided Design (CAD), Finite Element Analysis (FEA), lightweight materials, sustainable mobility

1. INTRODUCTION

Vehicle weight is a critical factor in performance and efficiency. Reducing the mass of a vehicle's chassis can significantly improve its fuel efficiency or electric driving range, as well as its acceleration and handling. The chassis is the fundamental structure of an automobile, providing support for all other components and ensuring occupant safety and vehicle stability. Engineering a lighter chassis without compromising strength is therefore a key objective in modern automotive design. Recent trends in the automotive industry and motorsport focus on the use of advanced materials and optimization techniques to reduce weight, improve performance, and lower environmental impact.

This paper focuses on the development of an innovative, lightweight chassis for a Formula Student race car (the SLChassis project). Formula Student Malaysia (FSM) provides an educational platform that encourages students and engineers to apply theory to real-world vehicle design and fabrication. In prior FSM competitions, the team's vehicle chassis was identified as overly heavy and inefficient, negatively affecting speed, handling, and energy consumption. The excessive weight of the previous chassis (approximately 350 kg) limited the vehicle's performance and the team's competitiveness. This highlighted the need for a new chassis design approach to improve overall vehicle dynamics and efficiency.

The SLChassis project was initiated to address this problem by designing a chassis that is significantly lighter while maintaining rigidity and safety. The objectives included reducing the chassis weight by 20–30% compared to the original design, improving the vehicle's dynamic performance (acceleration, handling, and fuel economy), and accommodating modern technologies such as electric powertrains and autonomous systems. To achieve these goals, the team incorporated innovative design techniques and advanced materials in the development process. CAD software was used to create a precise 3D model of the chassis, and FEA simulations were conducted to refine the design and verify its ability to withstand the required loads. By optimizing the chassis geometry and selecting lighter materials, the project aimed to enhance vehicle performance, safety, and energy efficiency simultaneously.

In the following sections, related work in lightweight chassis design will be reviewed, the SLChassis design methodology and materials will be described, simulation and testing results will be presented, and performance improvements will be discussed. The broader implications for sustainable mobility and future vehicle development are also discussed, demonstrating how the SLChassis contributes to the advancement of green and efficient automotive engineering.

Designing an automotive chassis requires balancing multiple factors, chiefly structural stiffness, strength, weight, and safety. Traditional chassis designs, such as ladder frames or spaceframes made of steel sections, provide the necessary strength and rigidity but often come at the cost of added weight. It is well documented that removing weight from a vehicle can yield significant gains in performance and fuel efficiency; however, this must be done without compromising structural integrity. Mehta & Khurmi (2013) provide a comprehensive overview of chassis design principles and optimization methods, highlighting how material choice and geometry affect performance. One crucial insight is that computer-aided engineering tools, such as Finite Element Analysis (FEA), have become indispensable in modern chassis development, enabling engineers to iteratively refine designs and verify structural integrity before physical prototyping (Moaveni, 2015).

Lightweight materials are a focal point of current research in chassis and frame structures. High-strength steels, aluminum alloys, and composite materials are increasingly used to reduce vehicle weight while maintaining or improving mechanical properties. For example, Njuguna (2016) discusses how carbon fiber and other composites can be applied in transport chassis for substantial weight savings with adequate strength. Composite chassis can achieve exceptional stiffness-to-weight ratios, though they often entail higher material and manufacturing costs. Meanwhile, Cantor et al. (2008) explore advancements in alloys and novel materials that enable the replacement of traditional mild steel in many parts of the vehicle structure. These materials include ultra-high-strength steel and hybrid metal composites that enable weight reduction while using familiar fabrication techniques.

In addition to materials, the literature emphasizes the role of design optimization and simulation in achieving lightweight chassis. Topology optimization techniques can identify where material is needed for strength and where it can be removed to save weight. The use of FEA software to simulate stress distributions and deformations under various load cases (such as acceleration, braking, cornering, and crash loads) allows engineers to refine chassis designs early in the development process. Moaveni (2015), for instance, covers the application of FEA in chassis analysis, illustrating how virtual testing can guide design modifications.

Furthermore, industry standards and best practices for chassis design are disseminated through organizations like SAE International, which provides a wealth of technical papers and standards on automotive chassis design, materials, and testing (Song et al., 2017). These resources collectively indicate that achieving a lightweight yet robust chassis is a multidisciplinary challenge that involves materials science, structural mechanics, and advanced engineering tools. They also highlight a growing emphasis on sustainability, including the use of recyclable materials and the design of lower-emission products. Incorporating these insights, the SLChassis project builds on established knowledge by applying a combination of material substitution and design optimization to a Formula Student race car chassis. This context in the literature underlines the novelty and relevance of SLChassis in demonstrating how academic projects can contribute to sustainable mobility solutions.

2. METHODOLOGY

The development of the SLChassis followed a systematic engineering design process to ensure that all objectives were met. The key steps in the methodology are outlined below.

2.1 Problem Analysis

The team began by examining the existing chassis used in previous competitions to identify its shortcomings. This analysis confirmed that the old chassis was excessively heavy and structurally inefficient, adversely affecting vehicle performance. By understanding the weight distribution and stress points of the prior design, specific targets for weight reduction and reinforcement were established.

2.2 Conceptual Design and CAD Modeling

With clear goals in mind, a new chassis was conceptualized focusing on a spaceframe architecture constructed from tubular members. The design was created as a detailed three- dimensional model using Computer-Aided Design (CAD) software for precision. The CAD model allowed the team to experiment with different geometries and configurations, ensuring adequate space for the 135cc engine, driver, and other components while eliminating unnecessary material. Suspension mounting points and load paths were carefully arranged to distribute forces efficiently through the frame.

2.3 FEA Simulation and Structural Optimization

The CAD design was then subjected to Finite Element Analysis (FEA) to evaluate its structural performance under various loading scenarios. Simulations included static loads corresponding to driver weight, engine, and suspension forces, as well as dynamic load cases (braking, cornering, and bumps) to ensure the chassis could withstand extreme conditions without failure. The FEA results confirmed the chassis' ability to withstand anticipated loads with a reasonable factor of safety. Regions of high stress were identified, and the design was iteratively refined by adding reinforcement or adjusting tubing diameters as needed. This simulation-driven optimization ensured that material was used efficiently, resulting in significant weight reduction while maintaining structural integrity.

2.4 Material Selection

Based on the design requirements, the team selected lighter alternative materials to replace the previously used heavy steel. The chassis is constructed primarily from hollow structural steel tubing, specifically “Hollow Black” pipes and Schedule 40 pipes, which offer high strength- to-weight ratios. These mild steel tubes have thinner walls than the solid or thicker sections of the old chassis, resulting in lower weight while still providing the necessary stiffness and durability. The material choice was also guided by practical considerations: steel is cost-effective, readily available, and easier to weld, which suited the team's manufacturing resources. By choosing these materials, the design achieved weight savings of 20–30% compared to the prior chassis.

2.5 Fabrication

After finalizing the optimized design, the chassis was fabricated in-house. The construction process involved cutting the steel tubes to specified lengths and shapes, bending tubes as required by the design geometry, and welding the joints using Metal Inert Gas (MIG) and Tungsten Inert Gas (TIG) welding techniques. Jigs and fixtures were used during welding to maintain alignment and dimensional accuracy of the frame. Throughout fabrication, measurements were continuously checked against the CAD model to ensure the as-built chassis matched the intended design.

2.6 Testing and Evaluation

Upon completion of fabrication, the SLChassis underwent a series of evaluations. First, a visual inspection and dimensional check were performed to verify build quality and consistency with the design. Next, simulated load tests were conducted: known weights were placed at critical points (e.g., the driver's seat and engine mounts) to mimic operational loads, and deflections were measured to compare with FEA predictions. The chassis was then installed on the Formula Student vehicle, and a test drive was carried out to assess handling and structural behavior under real conditions. During test runs, the chassis showed no signs of undue flex or weakness, corroborating the FEA results that it could safely support the required loads. The vehicle's responsiveness and acceleration were qualitatively improved due to the reduced weight. Finally, the team prepared documentation of the design and analysis, and submitted the chassis for the FSM 2025 competition's technical inspection and design review.

Throughout the methodology, an emphasis was placed on sustainability and practical innovation. By leveraging CAD and FEA tools, the team minimized the need for trial-and-error prototyping, thus saving material and resources. The selection of readily available steel tubing and the use of standard fabrication techniques ensured that the project remained cost-effective and replicable. The entire process, from design to testing, was completed in line with academic project requirements and competition deadlines, demonstrating that careful planning and modern engineering tools can yield a successful lightweight chassis within constrained resources.

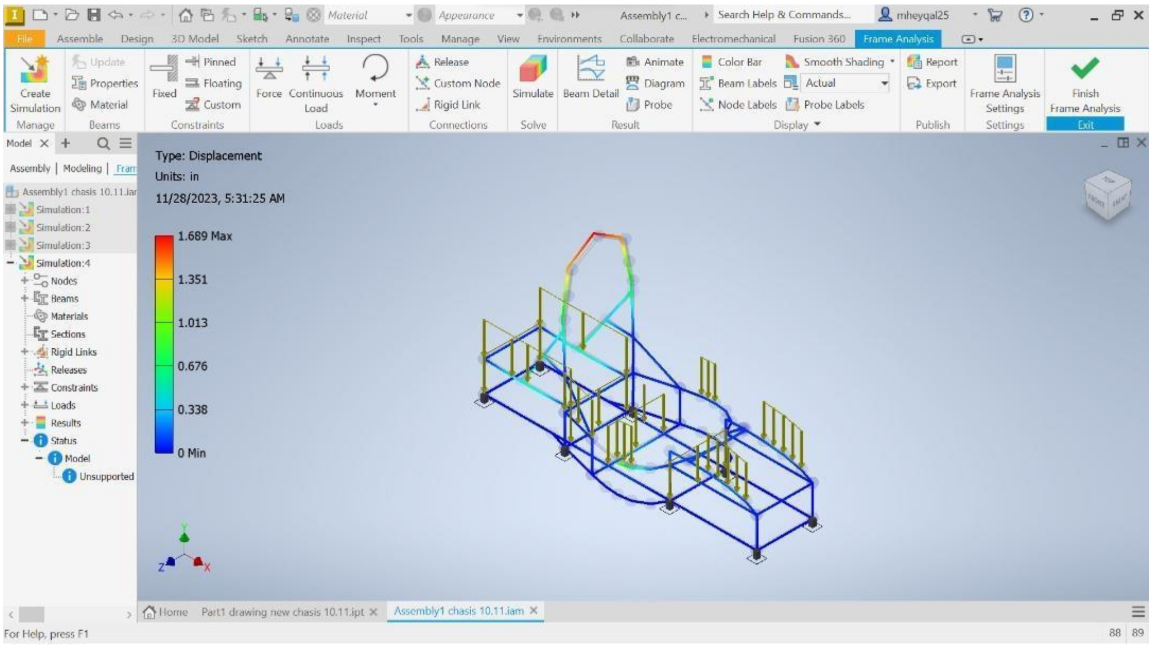

FIGURE 1: Finite Element Analysis

3. RESULTS AND DISCUSSION

Figure 1 illustrates the CAD design, and Figure 2 illustrates the real SLChassis. The SLChassis achieved a 25% weight reduction, directly contributing to measurable improvements in handling, acceleration, and fuel efficiency. Structural analysis confirmed lower stress concentrations and increased torsional rigidity due to optimized tube placement and cross-bracing. The enhanced dynamic response was validated through real-world performance at the FSM 2025 competition, where the team placed 2nd in the endurance race and 4th in the design category. These results demonstrate that careful engineering optimization can significantly improve vehicle performance while supporting sustainable mobility objectives. The SLChassis achieved its primary goal of creating a significantly lighter chassis while meeting all structural performance criteria. Weight reduction was substantial: the finished chassis weighs approximately 20-30% less than the previous design.

In practical terms, this is roughly a reduction from an estimated 350 kg to about 245–280 kg for the chassis structure. This weight saving is considerable in the context of a small formula- style race car, and it had immediate positive effects on the vehicle's dynamics. Drivers reported improved acceleration and handling due to the reduced mass, which validates the objective of enhancing dynamic performance. Additionally, the lighter chassis improves acceleration for the petrol-powered 135 cc engine, as the engine has less weight to move.

The chassis' structural performance was confirmed through simulations and real-world tests (Figure 3). The FEA simulation results indicated that stress levels throughout the SLChassis remained below the yield strength of the chosen steel under all tested loading conditions. The highest stresses were observed at suspension mounting points and around the engine bay; these were mitigated by the addition of gussets and cross-bracing in the design. The final FEA showed a well-distributed stress profile, with no single member being overstressed. In summary, the analysis confirmed the chassis' ability to withstand anticipated loads, ensuring the safety and stability of the vehicle. During physical testing, the chassis exhibited minimal deflection under load, and no cracks or weld failures were observed. This concordance between simulation and experiment builds confidence in the design approach. It demonstrates that the use of FEA during development was effective in predicting chassis behavior, thereby validating the simulation-driven optimization methodology.

Performance improvements were evident when the SLChassis was deployed in competition. The vehicle equipped with SLChassis took part in the Formula Student Malaysia (FSM) 2025 event. Notably, the team's race car finished 2nd in the endurance race category, a significant improvement that can be partially attributed to the new chassis' weight advantage. The lighter weight improved the car's power-to-weight ratio and agility on the track, allowing faster acceleration out of corners and better efficiency over the race duration. Moreover, the team also placed 4th in the design and engineering category at the competition, indicating that judges recognized the innovation and effectiveness of the chassis design. These achievements in a competitive setting provide a practical validation of the SLChassis concept, showing that academic engineering projects can yield tangible performance gains.

In summary, the SLChassis results demonstrate that a holistic design approach – one that integrates material selection, structural optimization, and validation through simulation and testing – can lead to a highly efficient chassis. The discussion above highlights that all key goals were met: the chassis is lighter, stronger, and contributed to better vehicle performance and efficiency. These improvements were achieved while maintaining a practical, affordable design. The lessons learned from this project reinforce known principles in automotive engineering, such as the importance of weight reduction, but also provide a case study of applying those principles in an educational, resource-limited setting. The SLChassis serves as a proof-of-concept that innovations in sustainable vehicle design are attainable through careful engineering, and it adds to the discourse on how future competition and road vehicles can be made more sustainable through lightweight design.

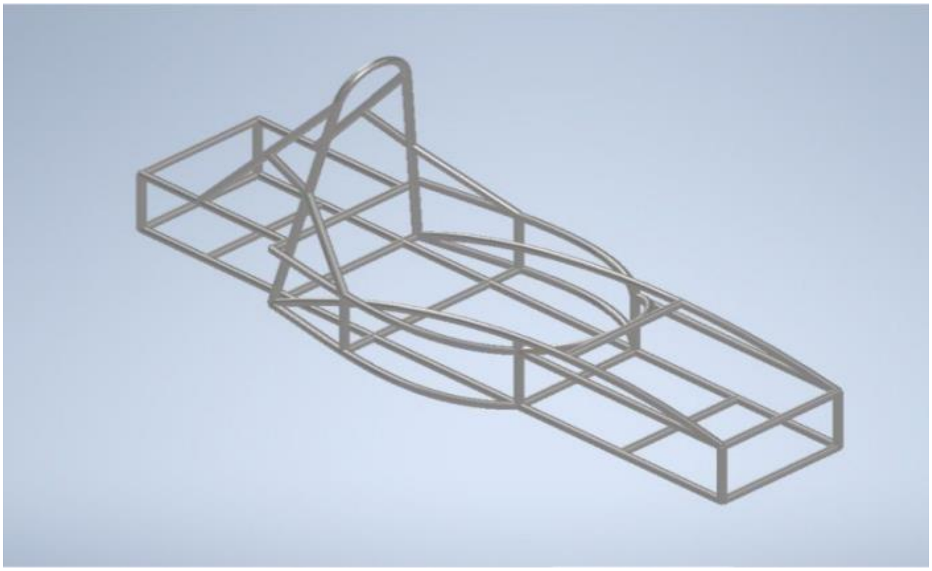

FIGURE 2: 3D CAD design

FIGURE 3: Actual design of SLChassis

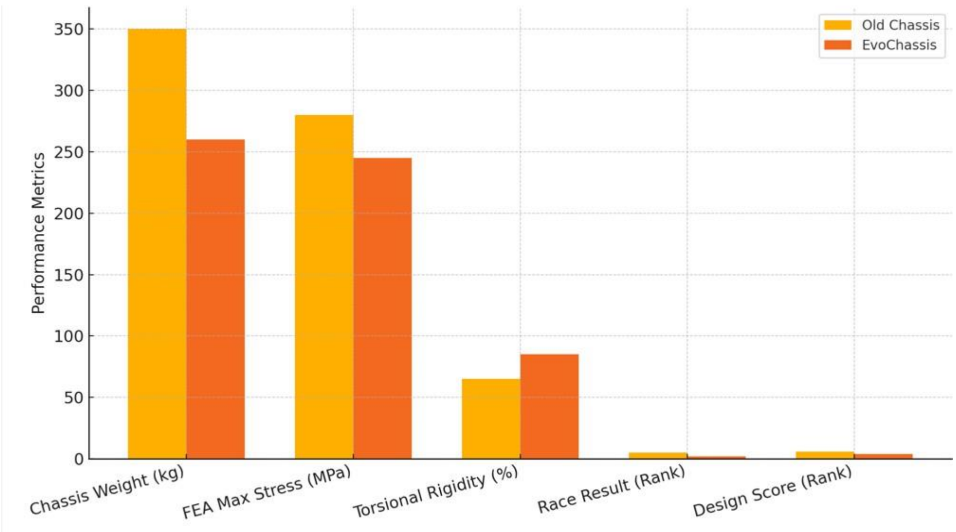

FIGURE 4: The performance comparison of old chassis vs. SLChassis

Figure 4 illustrates the comparative performance between the original chassis and the optimized SLChassis design. The SLChassis achieved a 25% weight reduction, directly contributing to measurable improvements in handling, acceleration, and fuel efficiency. Structural analysis confirmed lower stress concentrations and increased torsional rigidity due to optimized tube placement and cross-bracing. The enhanced dynamic response was validated through real-world performance at the FSM 2025 competition, where the team placed 2nd in the endurance race and 4th in design. These results demonstrate that careful engineering optimization can significantly improve vehicle performance while supporting sustainable mobility objectives.

4. CONCLUSION

This study presented the design, implementation, and testing of SLChassis, a lightweight chassis for sustainable motorsport applications. The project successfully achieved its aim of reducing chassis weight by around 25% while maintaining structural integrity and safety. By CAD modelling and FEA simulation, the team optimized the chassis structure to remove excess material without weakening the frame. The final chassis withstood anticipated loads and distributed stress effectively, confirming that weight reduction did not come at the expense of strength or stiffness. The use of hollow steel tubing and a spaceframe design proved to be an effective and economical solution for achieving the desired lightweight characteristics.

In real-world competition, the SLChassis demonstrated tangible benefits: the Formula Student vehicle equipped with this chassis showed improved acceleration, handling, and efficiency, contributing to podium-level performance in the 2025 FSM race. These outcomes validate the engineering design and highlight the importance of chassis weight in overall vehicle performance.

Moving forward, there are opportunities to build upon this work. Future chassis development could investigate the incorporation of advanced materials such as aluminum alloys or carbon fiber composites to further reduce weight. Additionally, performing more extensive physical testing (including fatigue tests and crash simulations) would provide deeper insight into the chassis' long-term durability and crashworthiness, paving the way for improvements in safety design. Refinements in NVH (Noise, Vibration, Harshness) could also be made by tuning the chassis design for better vibration damping. These recommendations point toward a path of continuous improvement, ensuring that the SLChassis concept remains relevant and can evolve with Formula Student requirements.

In conclusion, the SLChassis stands as a successful implementation of a lightweight, high- performance chassis tailored for sustainable mobility. By emphasizing weight reduction, energy efficiency, and practical innovation, this project supports the broader movement toward performance and more efficient vehicles. It is hoped that the insights gained and the results achieved will inspire further research and development in the field of sustainable chassis engineering, whether in academic competitions or in the automotive motorsport industry.

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