UNIVERSITY OF NIS FACULTY OF MECHANICAL ENGINEERING

THE TENTH INTERNATIONAL CONFERENCE
TRANSPORT AND LOGISTICS

https://doi.org/10.46793/TIL2025.141Z

til 2025

APPLICATION OF ENGINEERING ANALYSIS AND MODERN DESIGN TECHNIQUES IN FORMULA STUDENT RACE CAR CHASSIS DEVELOPMENT

***Dragan Živanić*[1], *Nikola Ilanković*[1], *Jovan Dorić*[1], *Mirko Katona*[1]**

[1)]*University of Novi Sad, Faculty of Technical Sciences, Department of Mechanization and Design Engineering*

ORCID iDs: Dragan Živanić https://orcid.org/0000-0003-2570-0727
Nikola Ilanković https://orcid.org/0000-0002-9110-4926
Jovan Dorić https://orcid.org/0000-0002-4532-4880
Mirko Katona https://orcid.org/0000-0002-2365-7975

Abstract

The development of modern race car chassis requires the integration of advanced engineering analysis and contemporary design techniques to ensure both performance and safety. This paper presents a comprehensive study of the application of numerical methods and parametric modeling in the design and optimization of a Formula Student race car chassis. The methodology combines computer-aided design (CAD), finite element analysis (FEA), and optimization strategies to evaluate and improve structural performance under realistic load conditions. The research begins with the conceptual modeling of the chassis, followed by the creation of a detailed three-dimensional model using Autodesk Inventor. The geometric model was prepared for analysis by discretizing it into a finite element mesh, with careful selection of element size and type to balance accuracy and computational efficiency. Boundary conditions and load cases, including torsional loading, bending under self-weight, and frontal and lateral impact simulations, were applied to replicate real-world operating conditions. The obtained results provided insight into stress distribution, deformation patterns, and safety factors across different scenarios. Iterative simulations were performed to ensure convergence and reliability of results. Critical zones of high stress concentrations were identified, guiding subsequent structural modifications. The optimization phase involved the addition of reinforcements to enhance torsional rigidity and impact resistance, followed by repeated FEA to validate improvements. The study demonstrates the essential role of engineering analysis and simulation tools in accelerating the design process and achieving reliable results with reduced prototyping costs. The findings confirm that modern chassis design in motorsport, especially within the Formula Student competition framework, cannot be effectively realized without systematic application of numerical methods. This integration provides safer, lighter, and more competitive vehicles, emphasizing the importance of coupling engineering analysis with innovative design practices in contemporary mechanical engineering.

Keywords:*race car chassis, formula student, finite element analysis, parametric modeling, structural optimization*.

1 INTRODUCTION

Engineering analysis in mechanical engineering represents a fundamental tool for understanding, designing, and optimizing mechanical systems. It encompasses a systematic approach to modelling physical phenomena using modern numerical methods and software tools. Engineering analysis enables engineers to predict the behaviour of components and systems under various loading conditions, temperatures, and operating regimes. As contemporary engineering increasingly relies on virtual prototyping and computer-aided simulations, such analyses have become essential for reducing development costs, shortening design cycles, and increasing the overall reliability of mechanical products.

In recent decades, the rapid development of computational capabilities has significantly advanced methods such as the finite element method (FEM), finite volume method (FVM), and other computational approaches widely described in modern mechanical design literature [1].

These numerical techniques enable precise assessment of structural integrity, stress distribution, thermal loads, vibration behaviour, and fluid-structure interactions. Their application allows complex engineering problems to be solved efficiently and with high accuracy, offering insights that previously required extensive physical testing and long development cycles. As a result, engineering analysis has become a cornerstone of contemporary design workflows across automotive engineering, aerospace, heavy machinery, robotics, and energy systems.

Within motorsport engineering—and particularly in student competitions such as Formula Student—engineering analysis plays a crucial role in achieving lightweight yet safe and structurally efficient vehicle designs. Formula Student competitions impose strict technical regulations that require teams to justify design decisions through quantitative engineering evidence. This creates a strong need for analytical and numerical evaluation of structural performance, especially for the chassis, which serves as the primary load-bearing component of the vehicle and directly influences safety, handling characteristics, overall stiffness, and dynamic performance.

The development of a race car chassis requires balancing conflicting objectives: minimizing mass while maximizing strength, stiffness, and crashworthiness.

Meeting these requirements demands the integration of advanced design techniques such as parametric modelling, digital prototyping, optimization strategies, and detailed

finite element simulations. Understanding the effects of torsional loading, bending due to static and dynamic loads, and impact forces is essential to ensure that the chassis satisfies both performance expectations and rigorous safety constraints.
The aim of this paper is to present a comprehensive study on the application of engineering analysis and modern design techniques in the development and optimization of a Formula Student race car chassis. Theoretical foundations of engineering analysis and its primary numerical methods are outlined, followed by a detailed description of the modelling, discretization, and validation procedures used in the study. Several critical loading scenarios are analysed to evaluate structural performance, identify areas of high stress concentration, and guide subsequent improvements. The findings emphasize the importance of simulation-based engineering in modern motorsport design and highlight the significant advantages of iterative numerical optimization over traditional empirical approaches.

2 THEORETICAL FOUNDATIONS

The fundamental concept of the finite element method assumes that a complex continuum can be approximated by a discrete system composed of finite elements interconnected at nodes [2]. Each element behaves according to a defined set of physical laws, for example Hooke’s law for linear elastic materials. The mathematical formulation originates from the differential equation of equilibrium and applies the principle of virtual work or a variational approach.
Discretization yields a system of linear or nonlinear algebraic equations:

$$[K] \cdot \{u\} = \{F\} \tag{1}$$

where:

- $[K]$ – stiffness matrix;
- $\{u\}$ – displacement vector;
- $\{F\}$ – external force vector.

The objective of static analysis is to compute stresses and deformations within a structural element. Internal stresses develop in a manner that ensures equilibrium within each portion of the volume, so that the sum of all forces acting on a finite volume is equal to zero. This principle enables rapid calculation for simple structural members—for example, using equilibrium to determine bending moments, shear forces, and subsequently normal and shear stresses in a beam.When the geometry becomes two-dimensional, the calculation increases in complexity, and even more so for three-dimensional bodies.The finite element method addresses this challenge by subdividing the body into many small elements connected at nodes. This process is known as discretization, and the resulting set of elements and nodes forms the mesh. Discretization is advantageous because the equilibrium laws only need to be satisfied for each finite element rather than for the entire body.
The result is a spatial mesh of finite elements that represents the geometry of the model.The user may freely select the mesh density, which directly depends on the size of the finite elements. The number of finite elements significantly affects computational requirements and total simulation time. Additionally, the smaller and more numerous the elements are, the higher the accuracy of the obtained results.

3 MODELLING AND MODEL PREPARATION PROCEDURE

Computer-Aided Design (CAD) represents an engineering process in which real-world engineering problems are represented using graphic and volumetric three-dimensional models created on a computer. This process produces a digital twin of the product that enables rapid modifications, analyses, calculations, and preparation of technical documentation.
The geometric modelling of the chassis began by defining the coordinate origin, where the X-axis represents the longitudinal axis and the Y-axis the front axle axis of the race car. A plane passing through this axis and the vertical Z-axis was defined as the reference (zero) plane of the model. Additional planes were introduced using offset distances from the zero plane, with parameters implemented for easier later adjustments.
The next step in parametric modelling involved defining and linking parameters with dimensional values such as lengths and angles. The newly introduced parameters were mathematically related and assigned appropriate names. Based on the defined reference geometry, standard tubular profiles were introduced using the Frame Generator tool [4], resulting in the final three-dimensional model of the analysed structure.
Mesh generation—i.e., discretization of the chassis model into a finite number of elements—was performed using the NASTRAN module, which allows the user to select element size, directly affecting simulation accuracy and computation time. Boundary conditions were defined according to the loading scenarios.
The loads were introduced based on an analysis of existing scientific literature [5, 8–13], and their magnitudes were obtained through calculations employing elementary mechanical principles and equilibrium equations.
The computations included loading cases specified in the Formula Student competition technical rulebook [6]. The analysed scenarios included:

- torsional loading of the chassis when the vehicle encounters a bump or pit;
- frontal impact loading;
- lateral impact loading.

These scenarios were selected as critical based on the safety requirements outlined in the competition rulebook. Safety validation of the chassis structure is demonstrated by analysing maximum stresses under frontal and lateral impact loading, as these cases closely represent the likelihood of structural failure during collisions, posing a risk to the driver.The torsinal loading case was selected to evaluate the vehicle’s performance characteristics. This analys enabled calculation of the torsional stiffness of the chassis. The resulting stiffness influences the vertical component of the wheel load, and by multiplying this force with the friction coefficient, the tyre grip can be estimated. These values are further used in determining the vehicle’s dynamic performance during cornering and braking, without requiring track testing.

4 RESULTS OF THE FINITE ELEMENT ANALYSIS

Following computational simulations for the defined loading cases, stress and deformation results were evaluated to identify locations of stress concentration. To validate accuracy, convergence of maximum stresses must be achieved. Convergence occurs when the stress values from two consecutive simulation iterations differ by less than 5%. Thus, simulations were repeated using smaller finite element sizes.

4.1 Torsional loading

For the torsional loading case, figure 1, the maximum stress in the first iteration was 320.8 MPa, and 331.5 MPa in the second iteration. The values converged with a difference of 1.65%, confirming accuracy and eliminating the need for further mesh refinement.

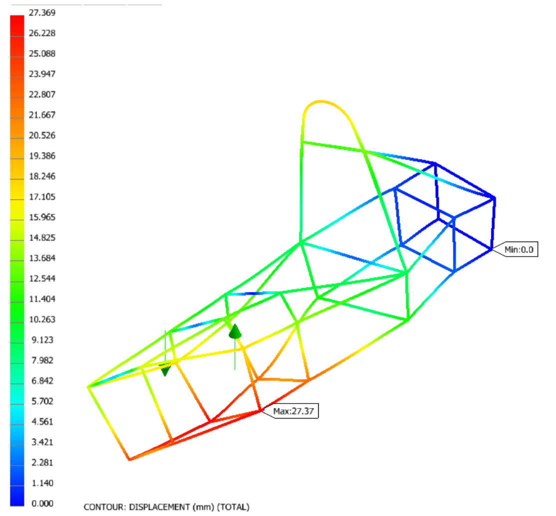

Fig. 1*Deformation values of the second iteration of chassis torsional moment loading*

Table 1 Simulation results for torsional loading

Quantity	Stress	Deformation
First iteration	320.8 MPa	27.369 mm
Second iteration	331.5 MPa	27.369 mm
Convergence	3.35%	0%

The resulting safety factor for torsional loading is:

$$\frac{460\ \text{MPa}}{331.5\ \text{MPa}} = 1.38 \qquad (2)$$

4.2 Frontal impact loading

For frontal impact loading, figure 2, the maximum stress in the first iteration was 121.8 MPa, and 120.3 MPa in the second. The difference was 1.23%, confirming convergence.

Table 2 Simulation results for frontal impact loading

Quantity	Stress	Deformation
First iteration	121.8 MPa	4.192 mm
Second iteration	120.3 MPa	4.192 mm
Convergence	1.23%	0%

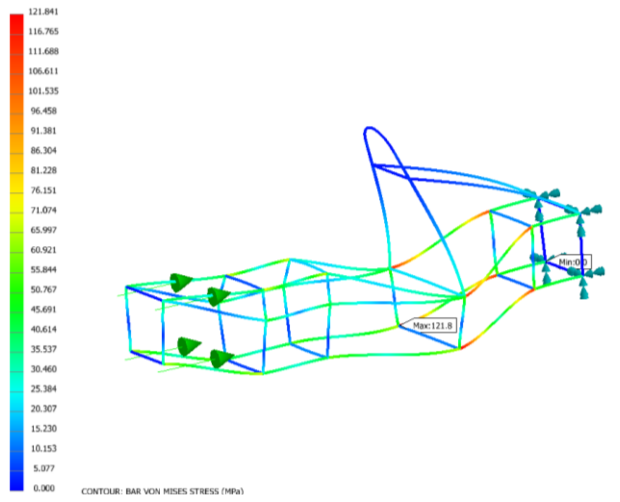

Fig. 2*Stress values of the second iteration of the front end impact load*

The safety factor for frontal impact loading is:

$$\frac{460\ \text{MPa}}{120.3\ \text{MPa}} = 3.8 \qquad (3)$$

The lowest safety factor—1.38—was observed for torsional loading. Therefore, design optimization of the chassis was carried out by introducing additional tubular members in the form of diagonal reinforcements [7].

4.3 Lateral impact loading

With the optimized chassis, the analysis was done for lateral impact loading, figure 3:

- First iteration: 298.8 MPa
- Second iteration: 316.6 MPa (convergence 5.95% → insufficient)

Thus, a third iteration was performed:

- Third iteration: 321.6 MPa
- Convergence with second iteration: 1.57%

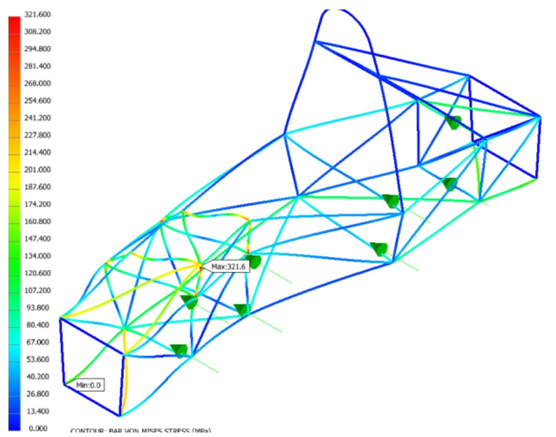

Fig. 3*Stress values of the third iteration of the lateral impact loading*

Table 3 Simulation results for lateral impact loading

Iteration	Stress	Deformation	Convergence
First	298.8 MPa	3.452 mm	—
Second	316.6 MPa	3.452 mm	5.95%
Third	321.6 MPa	3.452 mm	1.57%

The resulting safety factor is:

$$\frac{460\ \mathrm{MPa}}{321.6\ \mathrm{MPa}} = 1.43 \quad (4)$$

5 CONCLUSION

The results presented in this study confirm the importance of combining engineering analysis with contemporary design techniques in the development of Formula Student chassis structures. Through the integration of CAD modelling, parametric design, and finite element analysis, it was possible to evaluate multiple critical load scenarios and identify structural weaknesses that cannot be detected through conceptual modelling alone. The initial simulations revealed the most critical regions of the chassis as well as the loading conditions that govern overall structural performance. These insights enabled the introduction of targeted reinforcements, resulting in a measurable increase in torsional stiffness and improved safety factors under impact loading.

The optimization process demonstrated that even minor geometric modifications, such as the addition of diagonal tubular members, can significantly influence the distribution of stresses and the global rigidity of the structure. Iterative analyses ensured that the adopted improvements were validated through numerical convergence, confirming the reliability of the results. The optimized chassis exhibited enhanced mechanical performance, with the minimum safety factor increased to an acceptable level and the maximum stress reduced in the most critical area. This highlights the necessity of systematic optimization, particularly in applications where weight reduction, driver safety, and dynamic behaviour are equally critical design objectives.

The study also underlines the practical value of finite element analysis in reducing development time and minimizing physical prototyping. By accurately predicting structural behaviour under realistic loading conditions, FEA reduces the need for early-stage physical testing and allows teams to explore a wide range of design configurations within a short development cycle. This is particularly important in the Formula Student environment, where annual design constraints require rapid, iterative improvements based on quantitative engineering evidence.

Future research should focus on expanding the simulation framework to include dynamic analyses, crash energy absorption modelling, and multi-material chassis configurations. Incorporating composite materials or hybrid steel–composite structures may further enhance stiffness-to-weight ratios. Additionally, experimental validation through full-scale torsional rigidity testing, strain gauge measurements, and modal analysis would strengthen the correlation between the numerical model and real-world structural behaviour.

Overall, the research confirms that successful Formula Student chassis development depends on the systematic application of advanced engineering methodologies. The integration of parametric modelling, numerical simulation, and targeted optimization ensures the creation of safer, lighter, and more competitive vehicles. These approaches contribute not only to vehicle performance but also to the educational and research objectives of engineering students and academic institutions participating in the Formula Student competition.

ACKNOWLEDGMENT

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-137/2025-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project “Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad 2025” (No. 01-50/295).

REFERENCES

1. Shigley, J.E., 2020, Mechanical Engineering Design, McGraw-Hill, New York, ISBN 978-0-07-339821-1.
2. Đokić, R., Inženjerska analiza, Fakultet tehničkih nauka, Novi Sad.
3. Zienkiewicz, O.C., Taylor, R.L., Zhu, J.Z., 2013, The Finite Element Method: Its Basis and Fundamentals, Butterworth-Heinemann, Oxford, ISBN 0-7506-6320-0.
4. Ilanković, N., Savremene tehnike projektovanja transportnih sistema, Fakultet tehničkih nauka, Novi Sad.
5. Riley, W.B., George, A.R., 2002, Design, Analysis and Testing of a Formula SAE Car Chassis, SAE Technical Paper Series, ISSN 0148-7191.
6. Formula Society of Automotive Engineers, 2025, Formula Student Rulebook, Institution of Mechanical Engineers.
7. Smith, C., 2004, Racing Chassis and Suspension Design, Society of Automotive Engineers, Warrendale, PA, ISBN 0-7680-1120-5.
8. Kania, K., Verma, A., Babariya, R., Vasani, J., 2023, Design & Development of Formula Student Chassis, IRJET, Vol. 10, ISSN 2395-0056.
9. Khan, M.T., 2021, Design & Manufacturing of FSAE Chassis, IRJET, Vol. 3, e-ISSN 2582-5208.
10. Dionisius, F., Arif, I.N., Endramawan, T., Badruzzama, A.S., 2022, Material Selection and Analysis of Torsional Rigidity in Formula Student SAE Regulation, Journal of Engineering and Technological Sciences, Vol. 22, ISSN 2549-9815.
11. Zameer, S., Ali, S.A., Salman, T., Mohammad, K., 2022, Static Structural Analysis of Chassis in Compliance with International Rules of a Prototype Formula Styled Vehicle, IRJET, Vol. 9, e-ISSN 2395-0056.
12. Pathak, R., 2020, Analysis of Student Formula Car for Optimum Safety and Performance, IJRD, Vol. 5, ISSN 2455-7838, DOI:10.36713/epra2016.
13. Tamjidillah, M., Subagyo, R., Isworo, H., Nanlohy, H.Y., 2020, Modelling Analysis of High Effect of Main Roll Hoop on the Strength of Student Car Formula Chassis, Mechanics and Mechanical Engineering, Vol. 100, DOI: 10.5604/01.3001.0014.1959.

Contact address:
Dragan Živanić
University of Novi Sad
Faculty of Technical Sciences
21000 Novi Sad
Trg Dositeja Obradovića 6
E-mail: zivanic@uins.ac.rs