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Design of the Driver's Cockpit for Next Generation Vehicle (NxGV) 2025 Formula Car

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ABSTRACT – *This paper presents the structural and ergonomic design of the driver's cockpit for a student formula race car developed for the Next Generation Vehicle (NxGV) Challenge 2025. The cockpit, located centrally within the chassis alongside the engine bay, plays a critical role in ensuring driver safety and comfort during high-speed operation. The chassis was fabricated using low-carbon steel with MIG welding to meet the competition's material and manufacturing requirements. Driver anthropometric measurements were utilized to inform the initial design, ensuring compliance with dimensional regulations. A complete CAD model was developed using Autodesk Inventor 2024, and a Finite Element Analysis (FEA) was conducted to evaluate the structural integrity of the cockpit under a maximum applied force of 3000 N. The analysis revealed maximum deflections of 0.01589 inches along the Z-axis, 0.013 inches along the X-axis, and 0.0035 inches along the Y-axis. These results highlight the necessity for localized reinforcement, particularly at the front and rear ends of the chassis, to enhance crashworthiness and maintain driver protection in impact scenarios.*

KEYWORDS: Driver cockpit, low-carbon steel, finite element analysis, structural deflection, crashworthiness

1. INTRODUCTION

The Next Generation Vehicle (NxGV) Challenge 2025 provides an excellent platform for students to design, develop, and race formula-style vehicles with an emphasis on innovation, performance, and safety. The design and construction of a competitive race car require a careful balance between weight, strength, safety, and ergonomics (Riley & George, 2002; Mihailidis et al., 2009). Among the most critical components of any race car is the driver's cockpit, which serves not only as the operational interface but also as the primary safeguard during high-speed driving and impact scenarios (Ahmad et al., 2021).

In racing vehicles, the cockpit design plays an essential role in driver comfort, safety, and performance. The driver must be securely positioned to effectively control the vehicle while being protected from potential impacts. Additionally, the cockpit must comply with strict safety standards while accommodating the driver's unique physical dimensions (Gu et al., 2024). The purpose of this study is to describe the design and structural analysis of the driver's cockpit for a Formula race car developed for the NxGV Challenge 2025. Specifically, the design focuses on achieving the ideal driver positioning while ensuring a robust chassis capable of withstanding high forces encountered during racing. The process includes anthropometric analysis, computer-aided design (CAD), and Finite Element Analysis (FEA) to assess the structural integrity of the cockpit under expected loads. This study also discusses the methodologies used to develop the cockpit design, including material selection, fabrication techniques, and simulation methods. The goal is to optimize the cockpit's safety and performance while adhering to competition rules and regulations, ensuring the vehicle's competitiveness in the NxGV 2025 race.

2. METHODOLOGY

The development of the driver's cockpit for the student formula race car was carried out through a systematic engineering design process. The methodology comprised the following key stages.

2.1 Design Requirement Analysis

The design process began by looking at the regulations that have been set in terms of dimensions and characteristics of the cockpit outlined by the Next Generation Vehicle (NxGV) Challenge 2025. The vehicle must have a roll hoop and front and rear curves (Figure1). The front hoop must pass over the driver's head when the driver is in the vehicle. These two curves are intended to provide protection for the driver's head if the vehicle overturns during a collision. The driver's position is required to be in the middle of the vehicle frame and the engine, while the power transmission system is behind the frame. The cockpit was required to accommodate a male driver and ensure sufficient structural strength to withstand impact loads.

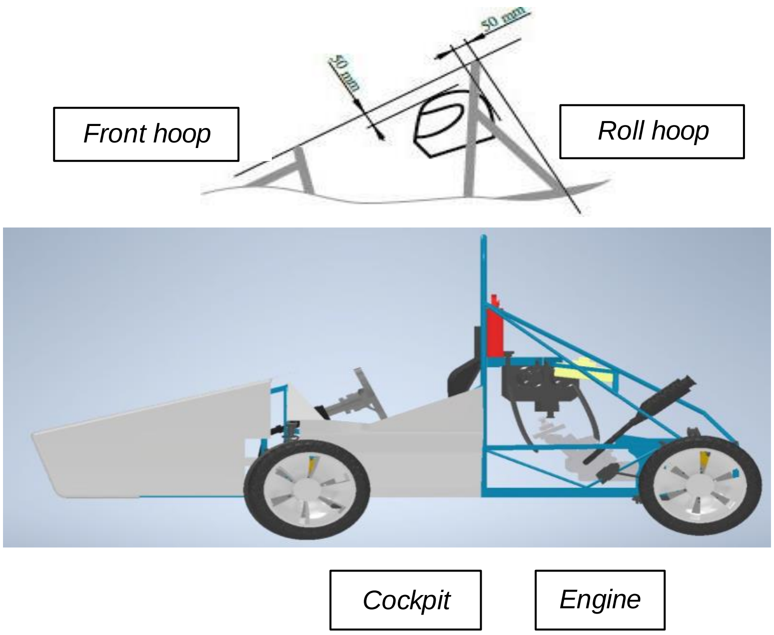

FIGURE 1: Position of the driving and engine compartment

2.2 Anthropometric Data Collection

A mock-up of the driver’s seating position was created to gather accurate anthropometric data. Measurements included driver height, arm reach, leg extension, shoulder width, and helmet clearance. These data were used as constraints and reference parameters in the digital modelling phase. The cockpit is in the middle of the vehicle's frame and shares the engine bay behind the driver. These two compartments contribute to the highest load on the frame of the car (Table 1).

TABLE 1: Vehicle load specifications

No.	Compartment	Load (kg)
1.	Cockpit	60 – 80
2.	Engine Bay	40 – 50
3.	Other components (frame, body, tires, suspension, power transmission, brakes, etc.)	150 – 200

From Table 1, the estimated total vehicle load can reach 250 kg - 330 kg for each competing vehicle. The cockpit contributes approximately 24% of the total vehicle's weight highlighting its significant contribution to the overall mass. Given its structural role and weight proportion, the cockpit is a critical component for ensuring driver safety, especially under dynamic and impact loading conditions. The cockpit must meet rigorous design requirements, not only to ensure structural integrity under static and dynamic loads but also to maintain driver survivability in events such as rollovers, frontal and lateral impacts and rear-end collisions. Its geometry, material selection, and weld joint quality all play a crucial role in performance under load.

2.3 CAD Modelling

The complete chassis, including the cockpit section was designed using Autodesk Inventor 2024. The cockpit was centrally located within the chassis and integrated with necessary components such as the steering column mount, pedal assembly space, and safety harness anchors.

2.4 Material Selection and Fabrication Process

Based on NxGV regulations and cost considerations, low-carbon steel was selected as the primary material for the cockpit (Table 2). This choice is justified by several key factors:

i. Excellent weldability, allowing for ease of fabrication and reliable joint strength.
ii. Widespread availability, reducing procurement time and cost.
iii. Adequate strength-to-weight ratio, meeting the structural demands of high load scenarios without excessive weight addition.
iv. Good mechanical properties, including sufficient ductility and tensile strength, enhance the frame's ability to absorb and distribute impact energy effectively.

While not as lightweight as aluminium or advanced composites, low carbon steel provides a balanced solution that meets performance, manufacturability, and regulatory compliance criteria within budget constraints.

TABLE 2: Low carbon steel properties

Material	Material Properties
Low Carbon Steel	Young Modulus, E = 207 GPa
	Poison ratio, ν = 0.292
	Density, ρ = 7850 kg/m^3

For the lower part of the vehicle frame, rectangular steel measuring 2 inches x 1 inch with a thickness of 1 mm is used to facilitate the connection of the frame to the base frame and the sides of the frame using ¾ inch pipe-shaped steel with a thickness of 1 mm combined with square steel measuring 1 inch x 1 inch with a thickness of 1 mm. The selection of this steel size is to facilitate the fabrication work to be carried out through manual cutting work and welding joints using MIG welding. Weld bead locations and joint overlaps were designed to minimize stress concentrations and ensure structural integrity.

2.5 Finite Element Analysis (FEA)

The digital model was subjected to Finite Element Analysis to evaluate the strength and deformation characteristics of the cockpit region (Figure 2). Boundary conditions were applied to simulate fixed constraints at suspension mounting points and load applications of up to 3000 N at critical zones, representing front and rear impact scenarios. Mesh sensitivity analysis was performed to optimize the accuracy and computational efficiency of the simulation. The resulting deformation values were extracted along the X, Y, and Z axes for further evaluation.

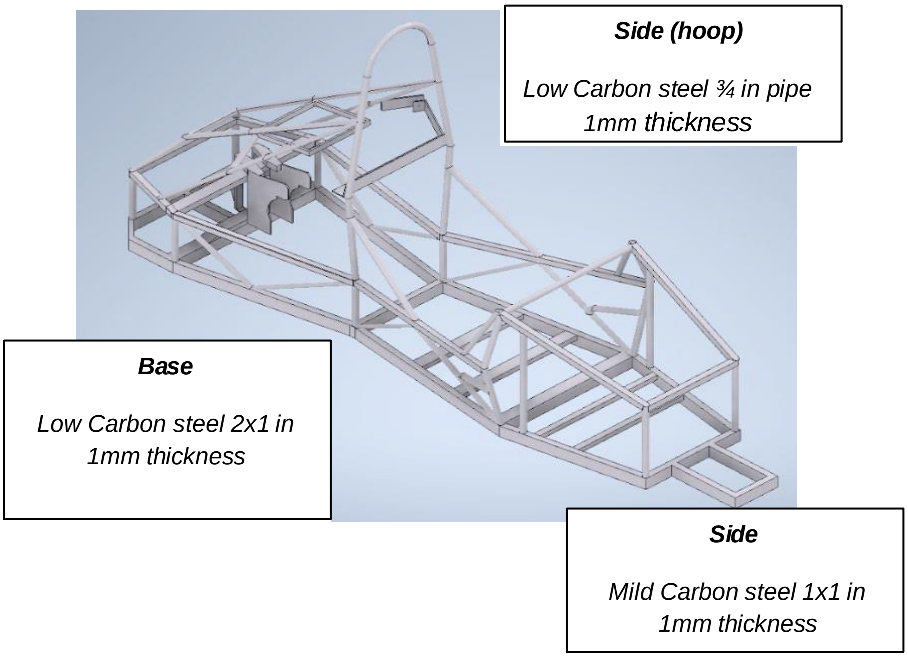

FIGURE 2: Position of the carbon steel connections on the base and side

3. RESULTS AND DISCUSSION

Finite Element Analysis (FEA) was conducted on the developed chassis model focusing on the cockpit region. The simulation applied a static structural load of 3000 N to represent crash scenarios from both the front and rear of the vehicle. The boundary conditions included fixed constraints at the suspension mounting points and the base of the frame. The color-coded results represent deflection values in inches, where red indicates the highest deflection and areas potentially requiring structural reinforcement. The analysis considered two load conditions applied along the Z-axis: a static load and an overturning scenario simulating a vehicle rollover during an accident (Figure 3). The results show that the side of the cockpit experiences the most critical upward deflection, measured at **0.01589 inches**. In contrast, the bottom of the frame does not experience a significant deflection, indicating minimal structural impact in that region.

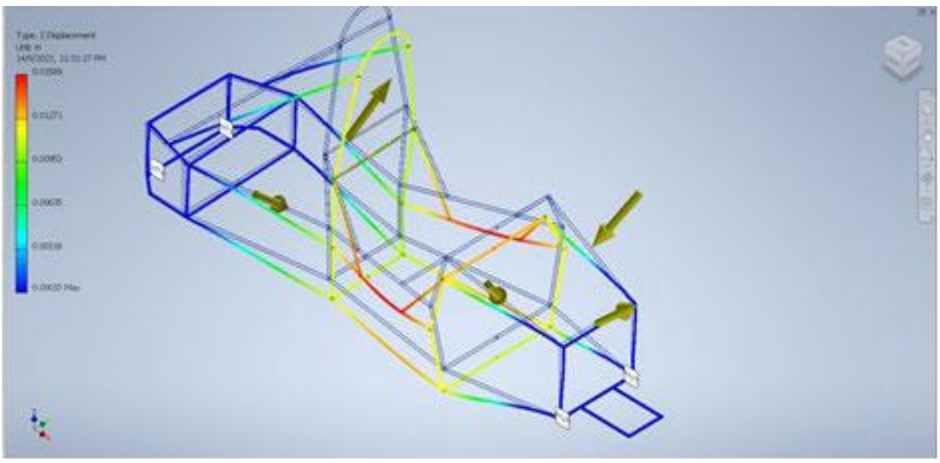

FIGURE 3: Analysis results on Z-axis

To assess the impact on the side of the structure, a pressure load was applied along the Y-axis (Figure 4). The analysis revealed that the cockpit experienced minimal impact, primarily due to the non-linear geometry of the lower frame, which is not straight from front to back. This design helps dissipate the force more effectively. However, a significant impact was observed in the engine compartment, where a deflection of **0.0035 inches** was recorded. Similar deflection patterns were also noted on both the left and right sides of the frame.

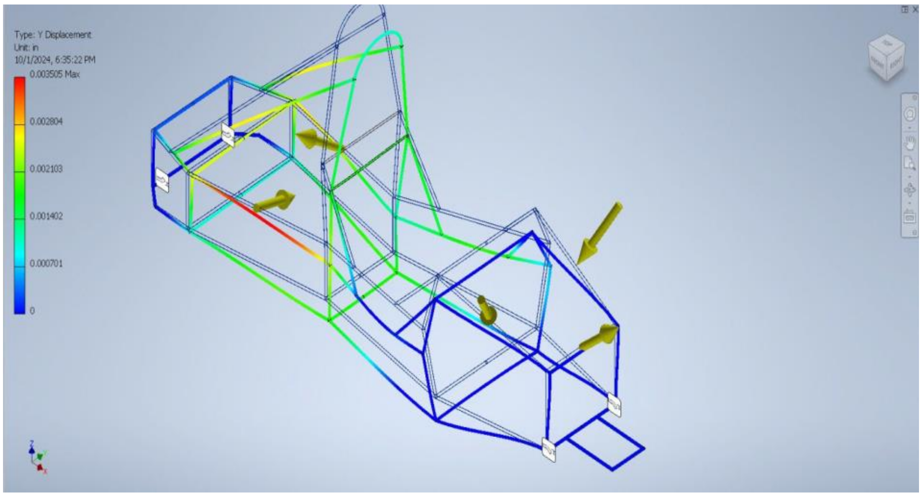

FIGURE 4: Analysis results on Y-axis

To evaluate the structural response to frontal impact, a load was applied along the X- axis (Figure 5). The analysis showed that the front section of the vehicle frame experienced minimal deflection, indicating good resistance to frontal forces. However, when the impact was applied to the rear, a notable deflection of **0.013 inches** was observed at the upper curved section of the frame. Despite this, the deflection remains within safe limits, as the driver's seating position is located below the height of the roll hoop, ensuring adequate protection in the event of a rear-end impact.

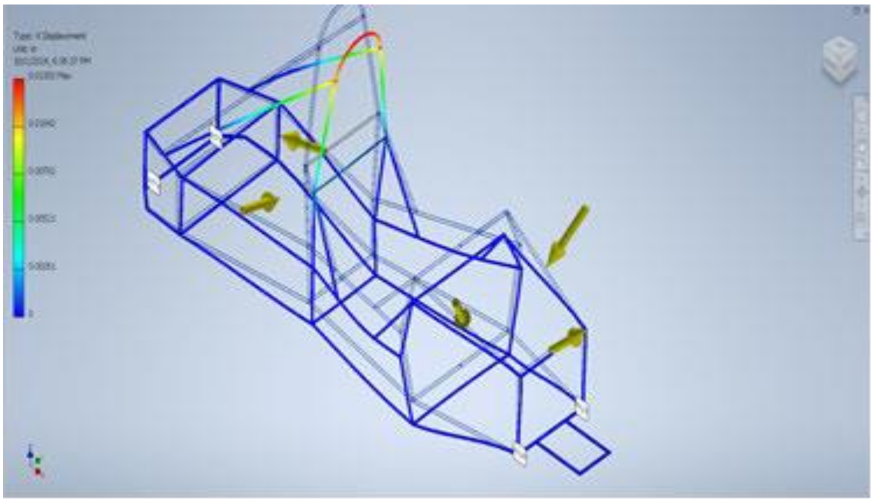

FIGURE 5: Analysis results on X-axis

Key results of the simulation are summarized in Table 3:

TABLE 3: Maximum deflection results by axis

Axis	Maximum Deflection (inches)
X	0.0130
Y	0.0035
Z	0.01589

The analysis revealed that the maximum deflection occurred along the Z-axis, followed by the X-axis (Figure 6). The Y-axis showed the least deflection, indicating minimal vertical distortion. The regions with the highest stress concentration were located near the front bulkhead and rear impact zones of the cockpit.

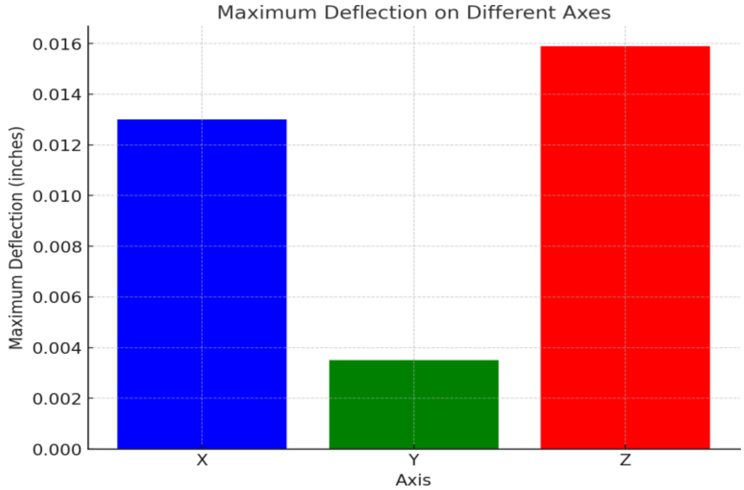

FIGURE 6: Graph showing the maximum deflection results by axis

The FEA results indicate that while the overall structure of the cockpit is within an acceptable range of deformation, certain areas require additional reinforcement to enhance the crashworthiness of the vehicle. The Z-axis deflection of **0.01589 inches**, although not critical, suggests potential vulnerability in frontal and rear impact scenarios, which are common in racing conditions. The use of low carbon steel in the chassis contributed to moderate flexibility, which can absorb energy in impact situations. However, excessive deflection in the Z-direction may affect driver safety if not properly managed. Structural reinforcements, such as cross- bracing and gusset plates, are recommended to reduce deformation in the high-stress areas identified. Moreover, the low deflection in the Y-axis supports the structural stability of the cockpit in vertical loading conditions, such as during vehicle landing or bump absorption. The design conforms well to anthropometric requirements, ensuring ergonomic placement of the steering wheel, pedals, and harness points, thus providing both comfort and safety for the driver.

4. CONCLUSION

This study focused on the design and structural analysis of the driver's cockpit for a student formula race car intended for the Next Generation Vehicle (NxGV) Challenge 2025. The cockpit was designed to meet both ergonomic and safety standards using low-carbon steel and MIG welding techniques. Finite Element Analysis demonstrated that while the design meets basic deformation tolerances, additional reinforcements are necessary at high-stress points, particularly along the Z-axis. The simulation results validated the initial assumptions regarding load paths and structural behaviour. The use of computer-aided design and FEA allowed for effective optimization of the chassis before fabrication. Future work will involve dynamic crash testing, further refinement of load distribution, and integration of safety systems such as a collapsible steering column and energy-absorbing structures.

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