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Innovative Engineering of the FRATEC EV Race Car: A Sustainable Approach to Performance and Safety

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ABSTRACT – *The FRATEC EV Race Car project by Politeknik Sultan Mizan Zainal Abidin (PSMZA) shows progress in eco-friendly car engineering. The car has a lightweight frame made from steel tubes, which makes it strong and safe. A special crash box protects the driver in front-end collisions. Tests showed the frame can handle a 3000 N impact without breaking. The car was built with precision, using welded steel tubes and carbon fiber sheets. Performance tests confirmed the car's safety and efficiency, with braking distances between 3.2 and 10.3 meters and good thermal management during acceleration. The electrical system worked well, meeting standards for battery voltage, voltage drop, CAN bus telemetry, and power efficiency. The FRATEC EV Race Car will compete in the NxGV Challenge Competition 2025, further demonstrating its innovative and sustainable design.*

KEYWORDS: Next Generation Vehicle (NxGV), electric vehicle, space-frame chassis, electric powertrain, fabrication

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1. INTRODUCTION

Politeknik Sultan Mizan Zainal Abidin (PSMZA) participates in the NxGV challenge through its specialized research and development division, the Formula Racing Automotive Technology Center (FRATEC). FRATEC was established to provide students with hands-on experience in advanced automotive engineering, fostering innovation in motorsports and sustainable mobility. The center integrates multidisciplinary skills such as mechanical design, electrical systems, electronics, aerodynamics, and manufacturing, aligning closely with current industry standards and future-forward technologies.

The 2025 project entry focuses on developing a lightweight, cost-effective electric race car prototype. This includes the design of a space-frame chassis, an efficient electric powertrain, and a safety-compliant structure – demonstrating the team's ability to meet competition requirements while showcasing FRATEC's commitment to education-driven engineering excellence.

The following are the project objectives:

1. To design the FRATEC EV race car chassis.
2. To analyze the structural and dynamic performance of the FRATEC EV race car.

Previous studies have emphasized the importance of lightweight chassis, efficient electric drivetrains, and sustainable design in competitive EVs. Research on space-frame chassis design confirms its advantage in providing structural rigidity while minimizing weight (Mohamad et al., 2017). FSAE and Baja competitions have similarly driven advancements in modular vehicle design (Dabhade et al., 2020; Devi & Dilip, 2014). Cooling and battery management systems are also critical for reliability and performance under dynamic load conditions.

2. METHODOLOGY

2.1 Design Phase

The methodology for developing the FRATEC EV race car prototype is divided into three main phases: (i) design, (ii) simulation & analysis, and (iii) fabrication & integration. Each phase incorporates engineering best practices, simulation tools, and compliance checks to ensure performance, safety, and efficiency. The design phase for the crash box and chassis of the FRATEC EV race car prototype utilizes Autodesk Inventor 2026 to ensure high performance, safety, and efficiency. Starting with conceptual design, engineers define specifications and visualize the layout using advanced CAD tools. Detailed modelling includes associative mirroring and patterning for precise design of the crash box and chassis. Material selection focuses on mild steel for strength and manufacturability. Structural analysis with finite element analysis (FEA) and optimization using Ansys software ensure robustness and effective impact absorption. Compliance checks throughout the phase guarantee adherence to standards, resulting in a well-optimized, safe crash box and chassis.

2.1.1 Chassis Design

The tubular space-frame chassis plays a critical role in the structural integrity and safety of lightweight electric vehicles. For this application, a chassis constructed using round mild steel tubes with an outer diameter of 25.4 mm and a wall thickness of 2.0 mm was selected (Figure 1). This material offers an optimal balance between cost, mechanical strength, and ease of fabrication, making it highly suitable for student-built or prototype electric vehicles.

Furthermore, the use of standard-sized round tubes helps reduce material waste and sourcing complexity. From a design perspective, the chassis employs a triangular truss geometry, a proven structural layout known for enhancing torsional rigidity while effectively distributing impact forces throughout the frame. This design not only improves vehicle handling but also contributes to the overall durability of the chassis under dynamic loading conditions.

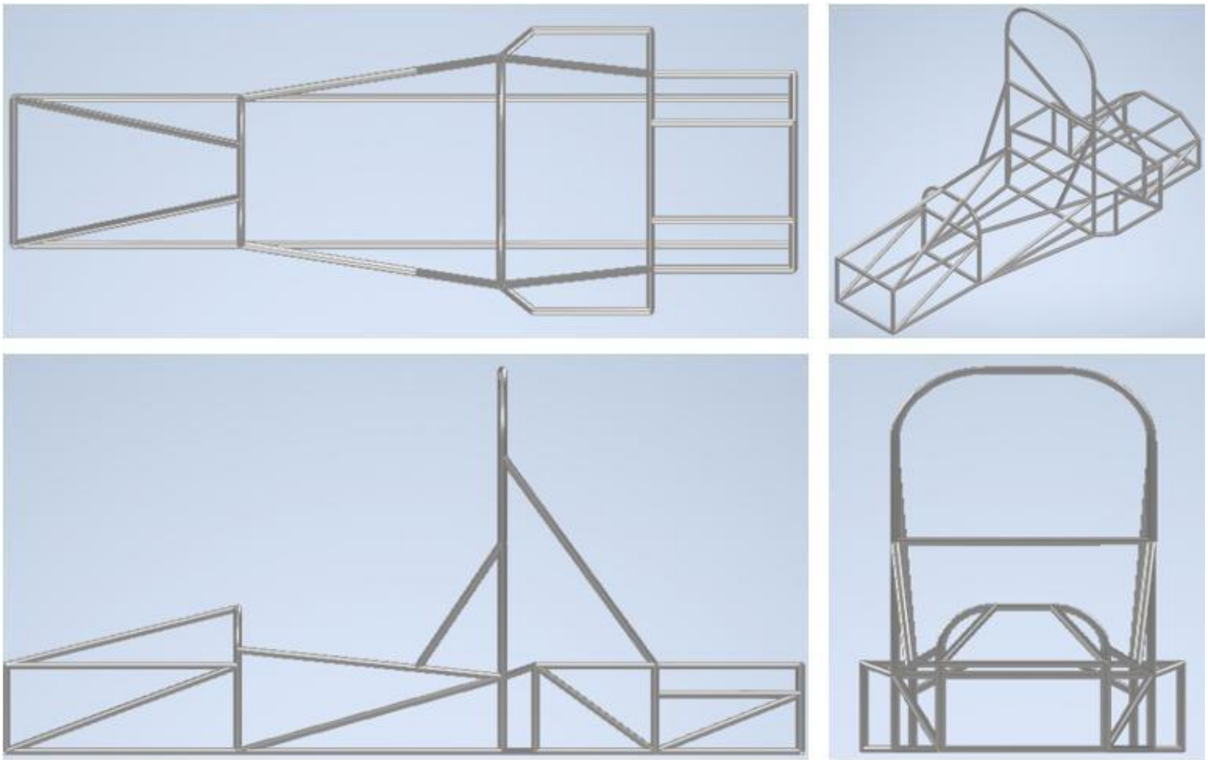

FIGURE 1: Chassis design FRATEC EV race car

2.1.2 Crash Box Design

To meet competition safety standards, a dedicated crash structure is integrated into the front of the frame. This crash box measures 200 x 200 x 300 mm and is fabricated using the same 2.0 mm thick mild steel material (Figure 2). Its primary function is to absorb the frontal impact energy during collisions, thereby protecting the driver and vital vehicle components.

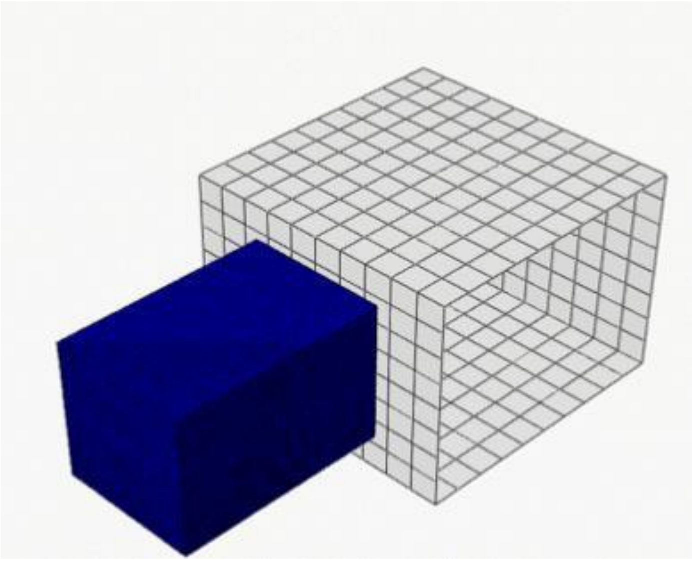

FIGURE 2: Crash box 3D design

2.2 Simulation and Structural Analysis

Analysis of the chassis structure and crash box was conducted using Autodesk Inventor and ANSYS software. An 8 mm tetrahedral mesh was applied to the chassis nodes to ensure accurate finite element discretization. A frontal impact load of 3000 N was applied to the crash box at three different speeds to simulate real-world collision conditions and evaluate the structural integrity of the design.

2.3 Fabrication Process

To complete the EV race car, the fabrication process begins with constructing the lightweight space-frame chassis using steel tubes, which are welded together for structural integrity. Mounting brackets for components like the battery, motor, and suspension are fabricated and welded onto the chassis. The body of the car is constructed from carbon fiber sheets, molded and laid up to ensure a lightweight yet strong structure. Electrical wiring is installed with high-current, insulated wires, ensuring secure connections. Suspension and drivetrain components are assembled and aligned. The car undergoes safety checks, including weld inspections, torque verification, and system functionality tests. Final adjustments are made based on test data for performance optimization.

2.4 Performance Testing

The testing and validation phase of the FRATEC EV race car was essential to ensure its functionality, safety, and performance. After assembly, several key tests were conducted, including braking trials, acceleration tests, and electrical system validation. Braking trials evaluated the car's stopping ability in dry conditions with an asphalt surface type, helping to fine-tune the brake system and improve balance and handling. Acceleration tests measured the car's performance from 0 to a suitable speed, ensuring the powertrain and battery systems with 92V met expectations. These tests also provided insight into the efficiency of the drivetrain under various conditions. Electrical system validation was crucial to ensure the car's electrical components, including the battery management system, motor controllers, and wiring, operated as expected. This validation ensured the car’s electrical systems could handle the demands of high-speed racing while maintaining efficiency and safety.

3.0 RESULTS AND DISCUSSION

3.1 Chassis Structural Analysis Result

The simulation results suggest that the frame structure can withstand the applied load of 3000N. The von Mises stress and displacement values are within acceptable limits, and the safety factor, although adequate, could be improved for enhanced reliability. The maximum Von Mises stress of 571.65 MPa is well below the yield strength of 857.48 MPa, ensuring the material remains within the elastic region and avoids permanent deformation. The maximum displacement of 19.87 mm suggests effective energy absorption during impacts, enhancing occupant safety. The safety factor of 1.5 confirms the design's reliability, providing a buffer against unexpected loads or material imperfections. This factor ensures the chassis and crash box can handle 1.5 times the maximum expected stress, contributing to overall vehicle safety and durability. Overall, the data reflects a well-engineered and safe design (Table 1).

TABLE 1: Chassis structural analysis results

Parameter	Result
Maximum Von Mises Stress	571.65MPa
Maximum Displacement	19.87mm
Yield Strength	857.48MPa
Safety Factor	1.5

3.2 Crash Box Analysis

The results of the crash box simulation conducted at three different impact speeds: 20 km/h, 40 km/h, and 60 km/h, are shown in Table 2. The simulation was performed to evaluate the structural performance of the crash box under frontal collision scenarios. Key parameters analyzed include displacement. These values provide insight into the crash box's ability to absorb impact energy and maintain structural integrity at varying impact severities.

TABLE 2: Crash box analysis results

Speed (km/h)	Force (N)	Displacement (mm)	Safety Factor	Remarks
20 km/h		25 mm	2.6	Mild deformation, well within safety limits
40 km/h	300N	50 mm	1.4	Moderate deformation, nearing failure thresholds
60 km/h		90 mm	0.92	Structural failure

3.3 Performance Testing Result

3.3.1 Braking Performance

Higher speeds result in longer stopping distances and increased brake temperatures (Table 3). At 20 km/h, the stopping distance is 3.2 meters, and brake temperatures are 50°C, while at 80 km/h, the stopping distance is 10.3 meters, and brake temperatures are 85°C. This highlights the need for safe driving and well-maintained brakes.

TABLE 3: Braking performance

Initial Speed (km/h)	Stopping Distance (m)	Brake Temperature (°C)
20	3.2	50
40	5.5	65
60	7.8	73
80	10.3	85

3.3.2 Acceleration Performance

The test data shows that acceleration times increase as speed rises, with a decrease in acceleration due to factors like increasing resistance and motor load (Table 4). Despite the 92Volt battery and 15 kW motor power being held constant, motor temperature rises, indicating potential efficiency loss. The voltage drops and heat buildup in the motor can impact overall performance. Maintaining optimal battery voltage and managing motor temperature is crucial for ensuring consistent power output and improving acceleration times. Effective thermal management and voltage monitoring are key to maximizing the performance of the 92V battery and 15 kW motor system.

TABLE 4: Acceleration performance results

Speed (km/h)	Time (s)	Acceleration (m/s²)	Motor Temperature (°C)
0-30	2.5	3.33	32
0-60	6.8	2.45	50
0-80	10.5	2.11	65

3.3.3 Electrical Validation Test

The electrical system's components generally perform well, with battery voltage, voltage drop, CAN bus telemetry, and power efficiency meeting standards (Table 5). However, temperature stability is a concern, averaging 50°C, which is quite high and requires attention. Ensuring effective thermal management is crucial to maintain the system's reliability and safety. Overall, while most components are compliant, addressing the high temperature stability will be essential for long-term performance and durability.

TABLE 5: Acceleration performance result

Component	Parameter	Result	Compliance
Battery Pack Voltage	Nominal 92V	Measured: 91.6V average	Passed
Voltage Drop (Peak)	<5% during acceleration	Acceptable threshold	Passed
CAN Bus Telemetry	All nodes communicating	Real-time data stable	Passed
Temperature Stability	Operating range 35°C -65°C	Quite high, average 50°C	Need attention
Power Efficiency	Minimum 85%	Measured: 88%	Passed

4.0 CONCLUSION

The FRATEC EV Race Car project by Politeknik Sultan Mizan Zainal Abidin (PSMZA) demonstrates significant advancements in sustainable automotive engineering. The car features a lightweight space-frame chassis made from round mild steel tubes, enhancing torsional rigidity and impact distribution. A dedicated crash box ensures driver safety during frontal impacts. Simulations confirmed the chassis' ability to withstand a 3000 N frontal impact load, with stress and displacement values within acceptable limits. The fabrication process emphasized precision and material efficiency, using welded steel tubes and carbon fiber sheets. Performance testing validated the car's functionality, safety, and efficiency, with braking trials showing stopping distances from 3.2 to 10.3 meters and acceleration tests highlighting the importance of thermal management. The electrical system performed well, meeting standards for battery voltage, voltage drop, CAN bus telemetry, and power efficiency. The FRATEC EV Race Car project meets competition requirements and exemplifies education-driven engineering excellence, providing valuable insights into competitive electric vehicle design and showcasing the potential for innovation and sustainability in automotive engineering.

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