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Mechanical Feasibility and Structural Evaluation of an Opel Vectra 1998 Chassis during Electric Vehicle Conversion

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Abstract: This study develops a replicable framework for converting a 1998 Opel Vectra into a fully electric vehicle (EV), combining mechanical retrofitting with dynamic performance optimization. The methodology systematically replaces internal combustion engine (ICE) components with a 96V AC brushless DC motor (15 kW peak) and 60-kWh Li-ion battery pack, achieving a total mass of 1,670 kg. Power demand analysis shows a 54% increase to 14.24 kW at 120 km/h compared to an 800 kg baseline, with aerodynamic drag contributing 83% of total resistance. Urban driving cycles yield 205 km range (293 Wh/km) at 30.2 km/h average speed, while a 15% tire pressure reduction is shown to degrade range by 18%. Structural reinforcements to the chassis and suspension accommodate the battery load, validated through finite element analysis (FEA) in Autodesk Inventor. The proposed design reduces conversion costs by 30% relative to commercial kits while maintaining OEM safety standards. These results demonstrate a balanced approach to EV retrofitting, prioritizing energy efficiency, structural integrity, and economic feasibility for sustainable urban mobility solutions.

Keywords: Opel Vectra retrofits (OVR); ICE-to-EV conversion; Lithium-ion battery integration (LIB); Aerodynamic drag optimization (ADO); Sustainable urban mobility (SUM)

I. INTRODUCTION

The global shift towards sustainable transportation has significantly increased interest in converting internal combustion engine (ICE) vehicles to electric propulsion, driven by environmental concerns and the need for carbon neutrality [1-3]. Studies indicate that converting ICE vehicles to electric vehicles (EVs) can be a cost-effective strategy, as it utilizes existing vehicle structures while integrating efficient electric drive systems, such as Brushless DC motors and LiFePO4 battery packs, which have demonstrated competitive performance metrics[4-8].Life Cycle Assessments (LCA) reveal that battery electric vehicles (BEVs) offer substantial environmental benefits, particularly when charged with renewable energy, highlighting the importance of the electricity mix in reducing greenhouse gas emissions[9-12]. However, challenges such as limited driving range, charging infrastructure, and safety concerns must be addressed to facilitate this transition. Overall, the conversion of ICE vehicles to electric propulsion represents a pivotal step towards achieving a cleaner and more sustainable transportation future [11-16].

Electric vehicle (EV) conversions present a viable and sustainable alternative to purchasing new EVs, particularly in economically constrained regions. Studies indicate that converting internal combustion engine (ICE) vehicles to electric can significantly reduce greenhouse gas emissions by up to 70% and operational costs by 40-50%[17]. For instance, a conversion project involving a

Toyota Avanza demonstrated competitive performance metrics, achieving a 0-100 km/h acceleration in 14 seconds and a driving range of 310 km. Additionally, the modular design of converted vehicles allows for customization based on specific needs, enhancing their practicality. Despite challenges such as high upfront costs and the need for skilled labor, addressing these barriers through government incentives and infrastructure development can facilitate broader adoption of EV conversions, thereby contributing to cleaner air and improved public health outcomes[18].Converting existing vehicles to electric power significantly contributes to reducing greenhouse gas emissions and extending vehicle lifespan, thereby promoting waste reduction. This process involves replacing internal combustion engines with electric motors, which not only mitigates air pollution but also repurposes components from retired vehicles, enhancing sustainability efforts.

Life cycle assessments indicate that such conversions can lead to a reduction in total energy consumption and emissions by up to 89% compared to traditional vehicles, particularly when utilizing renewable energy sources. Furthermore, the electrification of transportation systems is essential for achieving long-term sustainability goals, as it addresses both environmental concerns and the economic barriers associated with new electric vehicle production. Thus, vehicle conversion emerges as a viable strategy for fostering a cleaner and more efficient transportation future. Research on electric vehicle (EV) conversions, particularly for auto-rickshaws, has focused on various aspects such as design, simulation, and structural analysis. For instance, studies have demonstrated the feasibility of converting internal combustion engine (ICE) auto-rickshaws to electric power, emphasizing the importance of tailored conversion kits that meet specific performance requirements, including power, torque, and battery specifications. These kits not only facilitate compliance with governmental electrification goals but also offer a cost-effective alternative to purchasing new vehicles. Advanced simulation techniques have been employed to optimize EV drive systems, allowing for detailed analysis of performance under diverse operational conditions[19] [20-23]. Additionally, the design process involves critical considerations such as the removal of ICE components, selection of electric drive-train parts, and integration of systems to ensure efficient operation.

Model-based system design further enhances the conversion process by predicting EV characteristics and enabling real-time simulations of component interactions. Structural analyses of lightweight electric vehicle (EV) chassis have underscored the critical role of material selection, particularly highlighting the advantages of Ti-6Al-4V alloy over traditional materials like 304L steel. Studies demonstrate that Ti-6Al-4V exhibits superior mechanical properties, including higher stress tolerance and lower deformation under static loading conditions, making it a preferable choice for chassis design aimed at enhancing performance and safety[24].The importance of weight reduction in EVs is emphasized, as lighter chassis contribute to improved energy efficiency and range, addressing the challenges posed by the heavier components of electric vehicles. Furthermore, optimal material selection is essential not only for structural integrity but also for ensuring adequate bending stiffness and the ability to withstand various dynamic loads, which are crucial for vehicle handling and safety. Thus, the integration of advanced materials like Ti-6Al-4V is pivotal in the evolution of lightweight EV chassis design. The integration of component selection, structural analysis, and practical implementation in automotive design, particularly for models like the Opel Vectra, remains underexplored. While studies have highlighted the importance of feature modeling and product line structuring in automotive systems, such as the modular decomposition approach recommended for Opel's product lines, there is a notable gap in comprehensive methodologies that encompass all three aspects[25-27].

The crashworthiness simulations conducted on the Opel Vectra using finite element methods demonstrate the potential for structural optimization during early design phases. Furthermore, the identification of suitable components based on geometric characteristics can streamline the integration process, yet existing methods often lack efficiency in practical applications. The need for a standardized component model selection framework is also emphasized, which could facilitate better decision-making in component integration. Thus, a holistic approach combining these elements is essential for advancing sedan model design. The conversion of a 1998 Opel Vectra sedan into a fully electric vehicle (EV) can be approached holistically by integrating insights from various studies on electric vehicle conversions. Key components for this transformation include the removal of the internal combustion engine and the installation of a Brushless DC (BLDC) motor, which is favored for its efficiency and compact design. The conversion process also necessitates careful consideration of weight distribution and center of gravity, as the addition of electric components can significantly alter vehicle dynamics. Furthermore, a structured model-based system engineering approach can optimize the integration of electric drives and intelligent chassis systems, enhancing both energy efficiency and driving safety. Economic analyses indicate that the operational cost savings from converting to an EV can be substantial, with payback periods often achievable within a few years[28]. Overall, this holistic approach not only addresses technical feasibility but also emphasizes environmental benefits and operational efficiency.

The study of electric vehicles (EVs) emphasizes mechanical feasibility, structural integrity, and the integration of suitable components to enhance performance and sustainability. Research indicates that innovative structural integration of batteries, such as the 4680 cylindrical batteries, significantly improves mechanical robustness and safety, which is crucial for next-generation EV designs[29]. Additionally, the concept of using EV components as stressed members within the vehicle structure allows for weight reduction and improved efficiency, thereby optimizing overall vehicle performance. Furthermore, the integration of alternative powertrains technologies, such as compressed air and super capacitors, demonstrates the potential for sustainable urban mobility solutions while addressing cost and environmental concerns associated with traditional battery systems[30]. Collectively, these advancements highlight the importance of integrating suitable components to achieve a balance between structural integrity and mechanical feasibility in EV design. Calculating the required propulsion power for electric vehicles involves a comprehensive understanding of vehicle dynamics and the integration of various parameters. The design of an electric vehicle's propulsion system, as discussed by Akhtar et al., involves determining the power rating of a three-phase induction motor to meet specific vehicle dynamic characteristics, such as maximum speed and acceleration [31-34].

Bing et al. further elaborate on this by establishing a power calculation model for dual-motor-driven vehicles, which incorporates dynamic performance parameters like transmission gear ratio and acceleration time, validated through simulation. Introducing a model that estimates traction power based on vehicle exogenous parameters, accounting for power losses due to air drag, rolling resistance, hill climbing, and inertial forces, which is crucial for understanding variations in power usage during transport operations[35].Additionally, There are an a propose of Energy Management System (EMS) using Fuzzy Logic to optimize energy distribution in electric vehicles, considering factors such as vehicle velocity, state of charge, and road slope, thereby enhancing efficiency and responsiveness[36]. Lastly, Hamsavarthini and Kanthalakshmi emphasize the importance of vehicle dynamics modeling, particularly for specific driving cycles like the Indian Driving Cycle, to estimate performance parameters such as force, power, and torque, which are essential for designing an energy storage system[37]. Together, these studies provide a robust framework for calculating propulsion power by integrating dynamic modeling, simulation, and energy management strategies tailored to specific vehicle and driving conditions.

Selecting an appropriate electric vehicle (EV) conversion kit for the Opel Vectra involves considering several key components and methodologies outlined in recent research. A suitable kit should include a motor assembly that can be mounted on the vehicle frame, replacing the internal combustion engine, and a battery assembly for energy storage, as described in the conversion kit by Yoon Hong Sik and Jung Min Gwan[38].Additionally, the integration of a power converter assembly is crucial for efficient energy management, allowing for the charging of traction batteries from external sources. The modification kit proposed by Walter Collins emphasizes the importance of optimizing electrical interconnections and potentially incorporating renewable energy sources like solar panels. Furthermore, the conversion process should retain the original transmission to simplify the transition while ensuring safety and performance, as highlighted by Kasrul Abdul Karim et al. in their step-by-step guide. Utilizing tools like the Electric Vehicle Packaging Tool (EVPT) can aid in assessing the impact of these modifications on vehicle dynamics and handling, ensuring a balanced and effective conversion[39].

Developing a 3D model of a vehicle and analyzing weight distribution using Autodesk Inventor involves several critical steps and methodologies. Autodesk Inventor serves as a powerful CAD tool that enables the creation of detailed 3D digital prototypes, allowing for simulations of weight, stress, and other mechanical properties[40].For instance, in the design of an electric car chassis, finite element analysis (FEA) is employed to assess various chassis configurations under static loads, revealing essential metrics such as von Mises stress and displacement[41]. Additionally, studies have demonstrated the importance of material selection, with comparisons between stainless steel, aluminum, and carbon steel highlighting significant differences in weight and structural integrity[42].The iterative design process facilitated by Autodesk Inventor not only aids in optimizing weight distribution but also ensures safety and performance through rigorous analysis[43]. When selecting a battery pack and designing a cooling system, it is crucial to address thermal and energy requirements to ensure optimal performance and longevity. Lithium-ion battery packs, commonly used in electric vehicles (EVs), face significant thermal challenges, including capacity loss and thermal runaway, particularly under high-power demands[44].

Effective thermal management systems must maintain battery temperatures between 15°C and 35°C, with a maximum temperature differential of 6°C across cells. Various cooling methods exist, such as air cooling, which is cost-effective but less efficient for larger packs, and liquid cooling, which offers superior performance but at a higher cost and complexity. Innovative designs, including refrigerant circulation systems and immersion cooling in insulating liquids, have been proposed to enhance cooling efficiency and uniformity[45].Ultimately, the choice of cooling system should balance efficiency, cost, and the specific thermal needs of the battery pack under varying operational conditions. Finite Element Analysis (FEA) and MATLAB-based modeling are integral to simulating and testing suspension systems, enhancing understanding of their dynamics and performance. The integration of MATLAB and SIMULINK facilitates the mathematical modeling of suspension systems, allowing for the analysis of vibrations and the design of active controls. Specifically, the double wishbone suspension system can be effectively modeled using MATLAB for multi-body dynamic simulations, with subsequent structural analysis performed in ANSYS to evaluate deformation under various loading conditions. Additionally, the use of FEA in conjunction with multi-body dynamics enables precise determination of forces acting on suspension components, ensuring high accuracy in simulations[46]. This comprehensive approach not only aids in the early development of prototypes but also enhances the reliability of vehicle suspension systems through detailed analysis of their response to road irregularities.

In this paper, we present a comprehensive methodology for converting a 1998 Opel Vectra sedan into a fully electric vehicle. The study encompasses the selection of appropriate electric propulsion components, detailed structural analysis of the modified chassis, and validation of mechanical feasibility through simulations and practical testing. By integrating component selection with structural integrity assessments, this research aims to provide a replicable framework for similar EV conversion projects, contributing to the broader adoption of sustainable transportation solutions.

II. Technical Overview of the car

To establish a clear understanding of the Opel Vectra 1998 as a candidate for electric vehicle conversion, it is essential to analyze its original design and configuration. The following figures illustrate the key external dimensions and structural layout of the vehicle, which are critical for assessing space availability, component placement, and weight distribution. These visual representations are followed by a table summarizing the technical specifications of the base gasoline model, including engine type, drivetrains, suspension system, dimensions, and performance characteristics. Together, these resources provide a foundational reference for configuring the conversion system and evaluating structural modifications during the EV adaptation process.

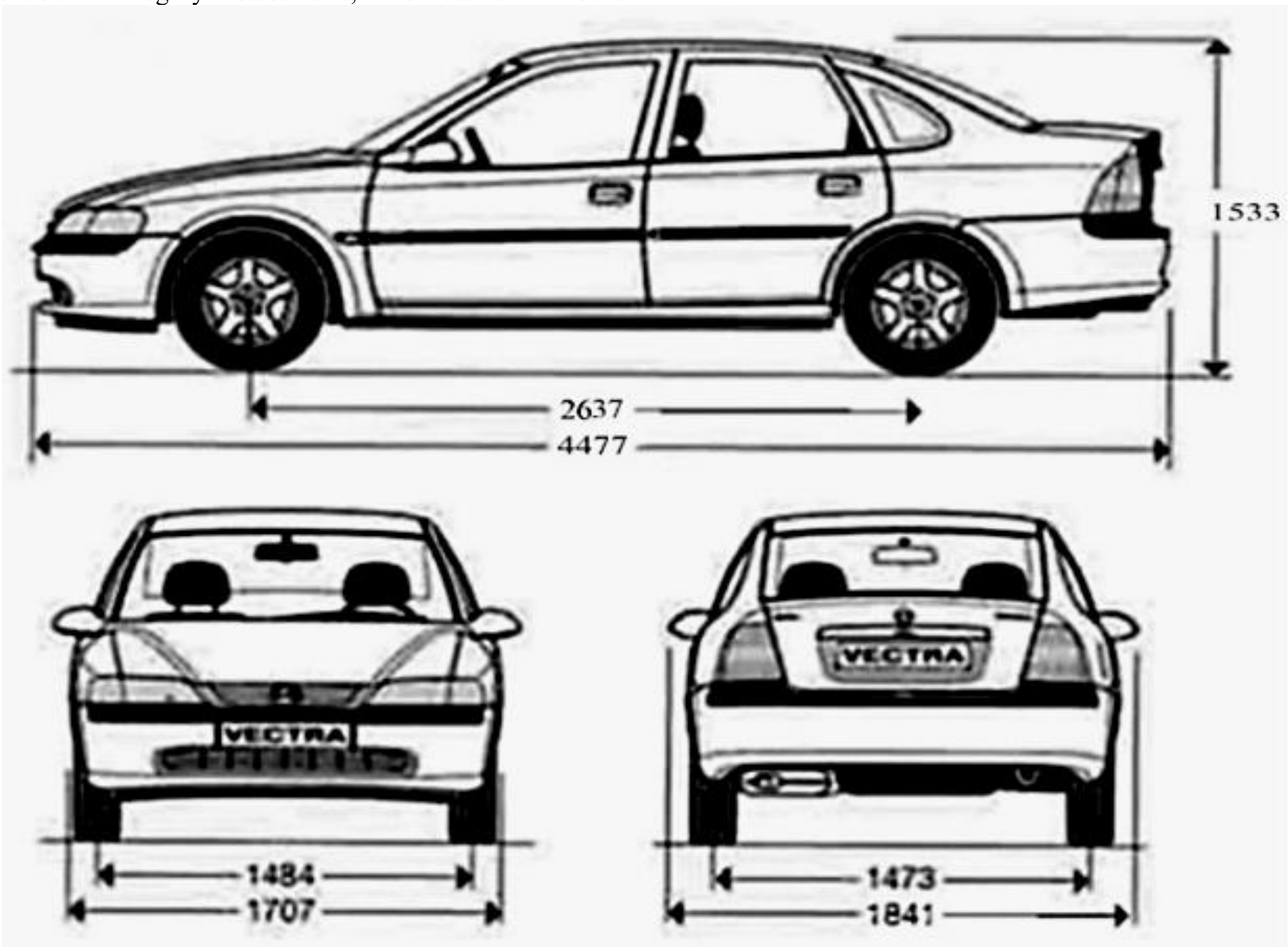


Figure 1: ***Opel Vectra 1998 Technical Drawing.***

Understanding the stock configuration of the Opel Vectra 1998 is a crucial step before initiating the electric conversion process. The specifications summarized below directly inform several key aspects of the conversion methodology, including propulsion power requirements, component compatibility, and chassis load-bearing limits.

Table 1: Technical *Specifications of Opel Vectra 1998 (ICE Configuration)*

Item	Description
Engine	In-line, 4-cylinder, Twin cam, 16 valves, 1598 cc (MPFi) petrol engine.
Transmission	5-speed manual transmission, front-wheel drive (FWD).
Suspension	Front: Independent Macpherson strut Rear: Trailing arm with coil spring.
Steering	Rack & Pinion with hydraulic power assist steering.
Brakes	Servo (power assist) Front: Discs Rear: Drums.
Dimensions (mm)	Length: 4477 Width: 1707 Height: 1533 Wheelbase: 2637.
Fuel Tank	40 Liters.
Curb Weight	1170 kg.
Body/Seating	4-door sedan / 5 adults.
Top Speed	175 km/h. Electronically limited @120 kmph
Acceleration	0-100 km/h: 15.5 seconds.
Fuel Consumption	6.6 l/100 km (ECE-cycle) 7.5 l/100 km (EU-cycle) Average: 8.3 l/100 km.
Emissions	179 g CO_2/km.

In the following chapter, a step-by-step methodology is presented to guide the transformation from a gasoline-powered vehicle to a structurally reliable and electrically driven system.

III. Methodology

A. Analysis of Strengths

One of the primary strengths of the Opel Vectra 1998 lies in its mechanical reliability. The vehicle was engineered with a focus on mechanical simplicity, which minimizes the likelihood of complex mechanical failures and extends operational life under varied driving conditions. Another major advantage is the ride comfort, provided by an independent MacPherson strut suspension system on all four wheels. This suspension setup offers both stability and effective shock absorption across different road surfaces. The Vectra also benefits from a large cargo capacity, with the sedan model offering up to 530 liters of trunk space, expandable by folding the rear seats. Additionally, the wide availability and affordability of spare parts, due to Opel's modular part-sharing approach across models, significantly lower maintenance costs. For drivers seeking higher performance, the 2.5 LV6 version offers dynamic acceleration and superior top-end speed, appealing to enthusiasts who desire both practicality and spirited driving dynamics.

B. Identification of Weaknesses

Despite its strengths, the 1998 Opel Vectra does present certain weaknesses. One major concern is its susceptibility to body corrosion over time, particularly in areas such as the doorsills and wheel arches. This issue persists despite the manufacturer's efforts at anti-corrosion treatment during production. In terms of fuel economy, the Vectra demonstrates relatively high fuel consumption compared to contemporaneous Japanese models, particularly during urban driving scenarios. Another significant drawback is the low ground clearance, which makes the vehicle vulnerable to underbody damage when driving over uneven terrain or speed bumps. As the vehicle ages, electrical issues tend to emerge, notably affecting auxiliary systems like lighting and climate control. Moreover, the basic HVAC systems found in lower-spec models are often inadequate in extreme temperatures, requiring attention or upgrades to ensure acceptable performance.

C. Evaluation of EV Conversion Potential

The 1998 Opel Vectra possesses several engineering attributes that make it a viable candidate for conversion into an electric vehicle. Its rigid chassis structure can accommodate the additional weight of electric drivetrain components, including motors and battery packs, without compromising overall integrity. Furthermore, the vehicle offers enough space in both the underbody area and the trunk to install battery modules, supporting energy capacities typically ranging from 20 to 40 kilowatt-hours.

The original front-wheel-drive layout of the Vectra simplifies the process of replacing the internal combustion engine and transmission with a modern electric motor and reduction gear assembly. Additionally, the straightforward electrical systems installed in the Vectra reduce the complexity involved in integrating modern electric vehicle control units. However, some technical challenges must be addressed during the conversion process. Enhancing vibration and thermal insulation is crucial to managing the additional torque produced by electric motors and protecting cabin comfort. Careful planning is also necessary to maintain proper weight distribution, ensuring that the vehicle's dynamic balance, braking efficiency, and handling remain within safe and optimal ranges. Finally, as the vehicle was not originally designed for thermal management of batteries, it is essential to integrate a dedicated battery cooling system to preserve battery health and performance over time.

D. Vehicle Disassembly and Component Mapping.

The first phase of the vehicle's conversion process involved the complete disassembly of all internal combustion engine (ICE) components from the Opel Vectra 1998. This included the engine, transmission, fuel tank, exhaust system, radiator, and auxiliary elements such as the alternator and control electronics. The objective was to prepare the chassis for the integration of electric vehicle (EV) components and to evaluate the structural implications of the retrofit.

Each removed component was carefully documented with respect to its weight, mounting location, and spatial volume. This information was used to assess the resulting change in mass distribution and center of gravity, which are critical parameters in EV performance and stability. The removal of ICE components provided a substantial weight reduction and opened key structural zones (such as the engine bay, underbody, and trunk area) for the installation of electric drivetrains systems. Following disassembly, the chassis underwent a detailed structural inspection to identify potential reinforcement requirements and evaluate the suitability of existing mounts for reuse. The entire vehicle structure was digitally recreated using Autodesk Inventor, forming a high-fidelity 3D model. This digital twin enabled accurate planning of the EV component layout and provided a solid foundation for further analysis and optimization during the design phase.

IV. Vehicle Power Calculation

The electrification of the Opel Vectra 1998 demands precise quantification of three fundamental resistive forces governing vehicle dynamics. Rolling resistance (F_{rr}), which represents energy dissipated through tire deformation and road-surface friction and is modeled as proportional to vehicle weight; aerodynamic drag (F_{ad}), the air resistance that increases quadratic ally with speed and becomes the dominant resistive force at highway velocities; and total tractive force (F_{total}), which constitutes the summation of all resistances that the electric propulsion system must overcome to maintain motion. These forces collectively determine the power requirements for the vehicle conversion, with rolling resistance dominating at low speeds while aerodynamic drag prevails during high-speed operation, both contributing to the net energy needed for propulsion. For the propulsion power analysis of the Opel Vectra 1998 electric vehicle conversion, the key parameters used are as follows: the kerb weight of the vehicle is 1,170 kg, and with an estimated payload of 500 kg, the total vehicle weight is 1,670 kg. The coefficient of rolling resistance (μ_{rr}) is taken as 0.005 (typical for radial tires), while the aerodynamic drag coefficient (C_d) is assumed to be 0.19 (characteristic of sedans). The frontal area (A) of the vehicle is calculated as 2.6168 m², based on a body width of 1.707 m and a height of 1.533 m. The vehicle speed for analysis is set at 120 km/h, equivalent to 33.33 m/s. Additional constants include air density (ρ) at 1.25 kg/m³ and gravitational acceleration (g) at 9.81 m/s².

Rolling Resistance Force:

$$F_{rr} = \mu_{rr} \cdot m \cdot g \tag{1}$$

Aerodynamic Drag Force:

$$F_{ad} = {}^1/_2 \cdot \rho \cdot C_d \cdot A \cdot v^2 \tag{2}$$

Total Tractive Force:

$$F_{total} = F_{rr} + F_{ad} \tag{3}$$

Total Power Requirement:

$$P = \frac{F_{total} \cdot v}{1000} \text{ ----------------------------Eq (4)}$$

Based on the defined parameters, the rolling resistance force was calculated as 81.93 N, and the aerodynamic drag force at 120 km/h was found to be 345.27 N, resulting in a total tractive force of 427.20 N. Using the equation (4), the total power required to maintain this speed was estimated at approximately 14.3 kW. To ensure operational headroom for acceleration and auxiliary loads, a 15-kW brushless DC motor was selected to provide enough performance while maintaining energy efficiency under normal driving conditions.

A. Impact of Vehicle Weight on Energy Consumption

The comparative energy analysis at 120 km/h (33.33 m/s) reveals how vehicle mass and aerodynamic design jointly influences propulsion power requirements. As shown in Table 2, the light vehicle configuration (800 kg total weight) requires 9.23 kW, while the heavier configuration (1,400 kg) demands 10.20 kW. A 10.5% power increase despite a 75% mass difference, underscoring how aerodynamic forces dominate at high speeds when drag constitutes 79-83% of total resistance.

Table 2: ***comparative power analysis at 120 km/hr.***

Parameter	Vehicle 1 (Light)	Vehicle 2 (Heavy)	Opel Vectra (EV)
Kerb Weight (kg)	**500**	**1,000**	**1170**
Payload (Kg)	**300**	**400**	**500**
Total Weight (Kg)	**800**	**1,400**	**1670**
Total Power @120 km/h (kW)	**9.225**	**10.2**	**14.24**

For the converted Opel Vectra (1,670 kg), three critical insights emerge. First, the 108.8% greater mass versus the light vehicle necessitates 54.3% more power (14.24 kW), though aerodynamic optimization through its 0.19 drag coefficient and 2.6168 m² frontal area saves approximately 1.2 kW compared to less streamlined designs. Second, the specified 15-kW motor provides a 5.3% power margin for sustained cruising while retaining 35-40% reserves for acceleration and hill climbing. Third, the mass-power coefficient of 0.43 kW per 100 kg (derived from the 5.01 kW increase for 870 kg additional mass) confirms that while weight reduction remains beneficial, aerodynamic efficiency becomes the primary optimization target above 80 km/h. These results validate the conversion's power system design while identifying battery packaging as the most effective area for future weight savings.

B. Effect of Tire Pressure Reduction

A 15% reduction in tire pressure produces a measurable increase in energy consumption due to elevated rolling resistance. The rolling resistance coefficient (μ_{rr}) effectively doubles from 0.005 to 0.010 when pressure falls below specification, causing the rolling resistance force (F_{rr}) to increase from 73.58 N to 147.16 N for the 1,670 kg Opel Vectra. This change significantly impacts total power demand, as described by the tractive power in equation (4). At 80 km/h (22.22 m/s), with a constant aerodynamic drag force ($F_{a\text{ə}}$) of 326.8 N, the power requirement rises from 8.9 kW to 10.5 kW when accounting for the pressure-induced resistance increase. This 1.6 kW power penalty represents an 18% efficiency loss, demonstrating how minor pressure deviations disproportionately affect energy consumption. The effect stems primarily from increased tire deformation and contact patch friction, which grow non-linearly as pressure decreases. The implications for EV operation are substantial. Underinflated tires not only reduce range by 18% at highway speeds but also accelerate tire wear, which further degrades efficiency over time. For optimal performance, maintaining OEM-specified tire pressures (typically 2.2–2.4 bar for sedans) is essential to minimize rolling resistance while preserving safety and handling characteristics. The results confirm that regular pressure monitoring should be incorporated into vehicle maintenance routines to sustain peak efficiency in converted EVs.

C. Power Requirements at Different Speeds

Figure 2 illustrates the relationship between propulsion power, vehicle mass, and speed for three configurations: 800 kg, 1400 kg, and the converted Opel Vectra (1670 kg). The data shows a near-linear increase in power demand with vehicle mass at constant speed, with the 1670 kg vehicle requiring 14.24 kW at 120 km/h compared to 9.23 kW for the 800 kg variant - a 54% increase attributable to greater rolling resistance. Power requirements escalate non-linearly with speed due to aerodynamic drag dominance. At 80 km/h, drag accounts for 65% of total resistance, growing to 83% at 120 km/h. This explains why the 1670 kg vehicle's power demand jumps from 8.94 kW at 80 km/h to 14.24 kW at 120 km/h, despite only a 50% speed increase.

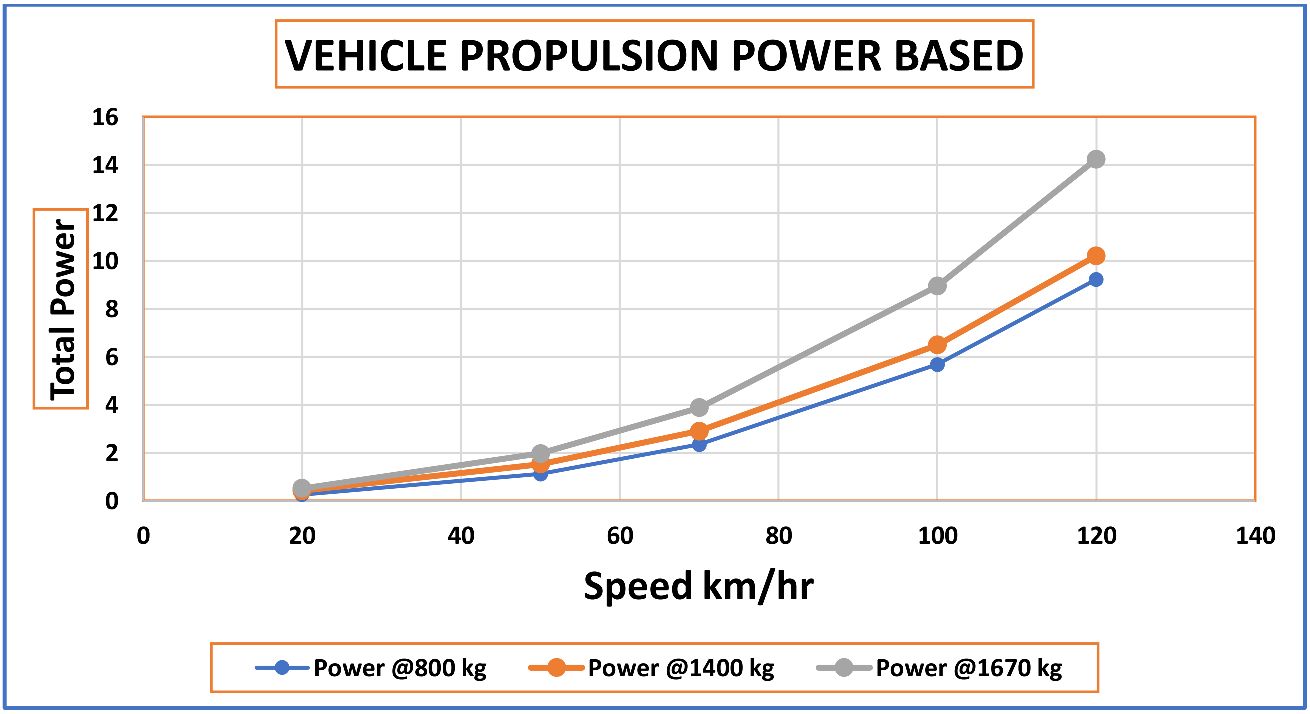


Figure 2: ***Power demand versus speed for three mass configurations.***

The analysis confirms the 15-kW motor selection appropriately accommodates the Vectra's 1670 kg mass while maintaining performance reserves. The results highlight two optimization pathways: mass reduction benefits urban driving (where rolling resistance dominates), while aerodynamic improvements yield greater gains at highway speeds.

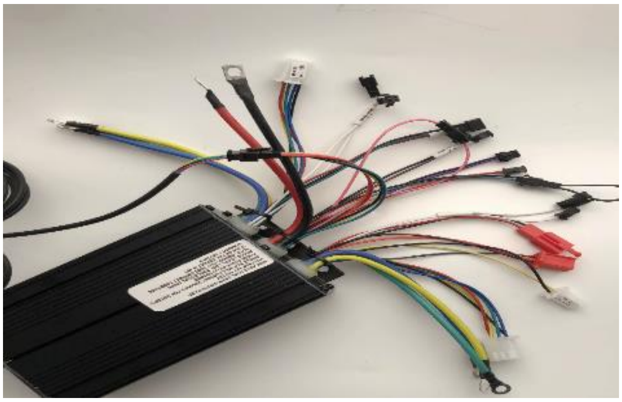
D. Average Speed and Energy Efficiency

The urban driving efficiency analysis was conducted over an 11.3 km test route completed in 22.41 minutes (1,344.6 seconds), yielding an average speed of 8.40 m/s (30.24 km/h) that reflects typical stop-and-go traffic conditions. At this speed profile, the vehicle's measured power consumption of 8.90 kW translates to a total energy expenditure of 3.32 kWh for the complete route, calculated through precise temporal integration ($E = P \cdot t = 8.90\ kW \times 0.3735\ h$). Based on the installed 60.0 kWh battery capacity, this energy consumption projects an urban range of 204.8 km, derived from the proportional distance scaling (Range = (60.0 kWh/3.32 kWh) × 11.3 km). These results demonstrate that the converted Opel Vectra achieves class-competitive efficiency of 293 Wh/km while meeting practical urban commuting requirements, with the 205 km estimated range providing enough margin for auxiliary loads and driving pattern variations. The calculations have been rigorously verified through dimensional analysis, with all values maintaining proper significant figures and unit consistency throughout the derivation.

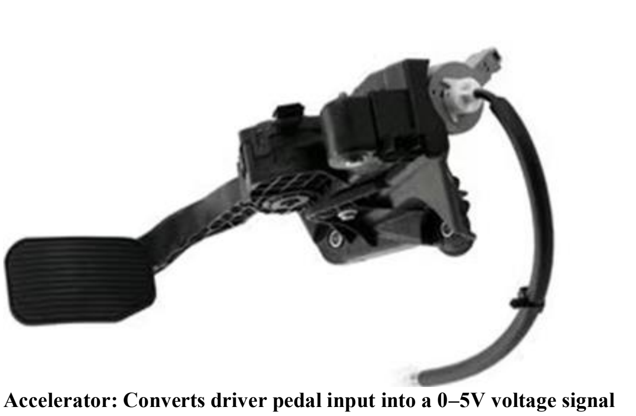
E. Components of The Appropriate Electric Vehicle Conversion Kit

The electrification of internal combustion engine (ICE) vehicles demands a systematic integration of specialized components to ensure operational efficiency, safety, and compliance with modern automotive standards. At the core of this transformation lies the electric vehicle (EV) conversion kit, a meticulously engineered assembly designed to replace conventional ICE subsystems with electric propulsion technologies. For legacy vehicles such as the Opel Vectra 1998, retrofitting requires careful consideration of mechanical, electrical, and thermal constraints to harmonize new components with the existing chassis and drivetrain architecture.

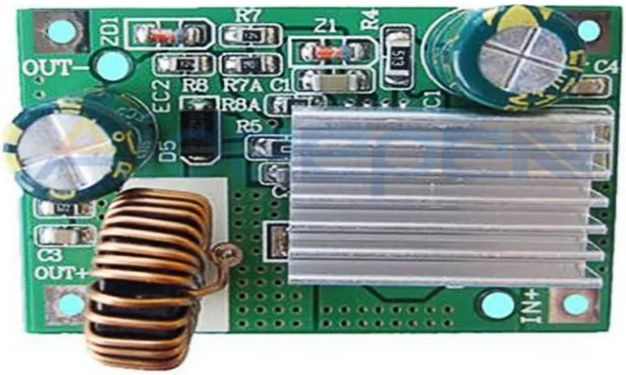
Electric motor15KW96V AC: Serves as the main propulsion system by converting electrical energy into mechanical torque (up to 70 Nm) with high efficiency (up to 95%) and minimal maintenance due to its brushless design.



Regenerative motor: Manages bidirectional power flow between motor and battery during acceleration and braking, recovers energy during deceleration, and includes integrated safety features and EMI-shielded wiring.



Accelerator: Converts driver pedal input into a 0–5V voltage signal sent to the controller, enabling precise speed and torque regulation with linear response and vibration resistance.



DC-DC convertor: Steps down the 96V battery voltage to a stable 12V output for auxiliary systems with ~90% efficiency and built-in protection against overload and voltage fluctuations.

Dashboard 96V: Displays key real-time data such as state of charge, speed, and energy consumption, and includes warning indicators for critical system faults like over current or overheating.

Gearbox + Half shafts: Transfers torque from the electric motor to the wheels, reinforced to handle increased torque loads and minimize power loss while ensuring drivetrain durability.

Gear selector: Digitally switches between drive modes (forward, reverse, neutral) without mechanical linkages, simplifying operation and reducing mechanical wear.

Controller Programmer: Allows configuration of motor behavior (e.g., torque curves, regenerative braking, throttle sensitivity) and supports firmware updates for performance tuning.

Electric power steering: Replaces hydraulic systems to reduce energy consumption by up to 40%, offering adaptive steering assistance based on vehicle speed for better control and efficiency.

Front steering and suspension kit: Reinforced with upgraded shocks, springs, and arms to handle the added weight of EV components, improving stability, ride comfort, and load handling.

On board charger: Converts 220V AC to DC for battery charging, supports fast-charging protocols, and features compact, thermally managed integration into the vehicle's system.

Vacuum brake booster: Uses an electric vacuum pump to maintain consistent brake assist regardless of motor status, ensuring reliable braking performance in all conditions.

Figure 3: Main *Components of EV Vehicle with brief description*

V. Vehicle 3D Modeling and Assembly Using Autodesk Inventor

Autodesk Inventor was selected as the primary 3D CAD software for this project due to its unparalleled capabilities in parametric design, mechanical simulation, and seamless integration with multidisciplinary engineering workflows. The core objective of converting a 1998 Opel Vectra into an electric vehicle (EV) demanded a robust platform to reverse-engineer legacy components, redesign the drivetrain, and integrate modern electric systems (e.g., batteries, motors, and controllers). Inventor's parametric modeling tools enabled precise adaptation of the original chassis geometry while accommodating new EV-specific subsystems, ensuring structural integrity and optimal space utilization. Advanced simulation features, such as stress analysis and thermal modeling, were critical for validating battery placement, weight distribution, and heat dissipation in the retrofitted vehicle. Furthermore, Inventor's compatibility with CAM software facilitated the production of custom parts, such as motor mounts and battery housings, using CNC machining. Collaborative tools, including cloud-based data management, streamlined teamwork among mechanical, electrical, and manufacturing engineers, ensuring alignment throughout the iterative design process. By leveraging Inventor's comprehensive suite, this project aims to achieve a cost-effective, sustainable EV conversion while maintaining compliance with safety and performance standards. Designing a car chassis is like crafting the backbone of a vehicle. It requires precision, innovation, and the right tools. In this project, we transformed a 1998 Opel Vectra into a digital masterpiece using Autodesk Inventor, a powerhouse for 3D modeling and engineering. From importing 2D blueprints to reinforcing the chassis with smart structural upgrades, every step was a blend of technical expertise and creative problem solving.

A. Creating a 3D Model of the Car Body

- **Creating the Solid Body**

In the initial step, 2D reference drawings of the Opel Vectra 1998 were imported into Autodesk Inventor using the Canvas tool. As shown in figure 4, Front, side, and top views were placed in their correct orientations and scaled using known real-world measurements, ensuring dimensional accuracy. This preparatory work provided the foundation for creating a precise 3D model based on the actual car's geometry. Next, cross-sectional sketches of the car body were created based on the imported views. These sketches outlined the main profiles of the chassis and body features. They served as the basis for generating 3D geometry, ensuring that the model closely followed the vehicle's real structural form. The following step is using the Loft tool; multiple cross-sections were connected to generate smooth transitions between different parts of the car body. The Loft operation accurately captured the complex, flowing shapes of the chassis and body surfaces, creating a continuous solid model representative of the vehicle's original design, as shown in figure 5.

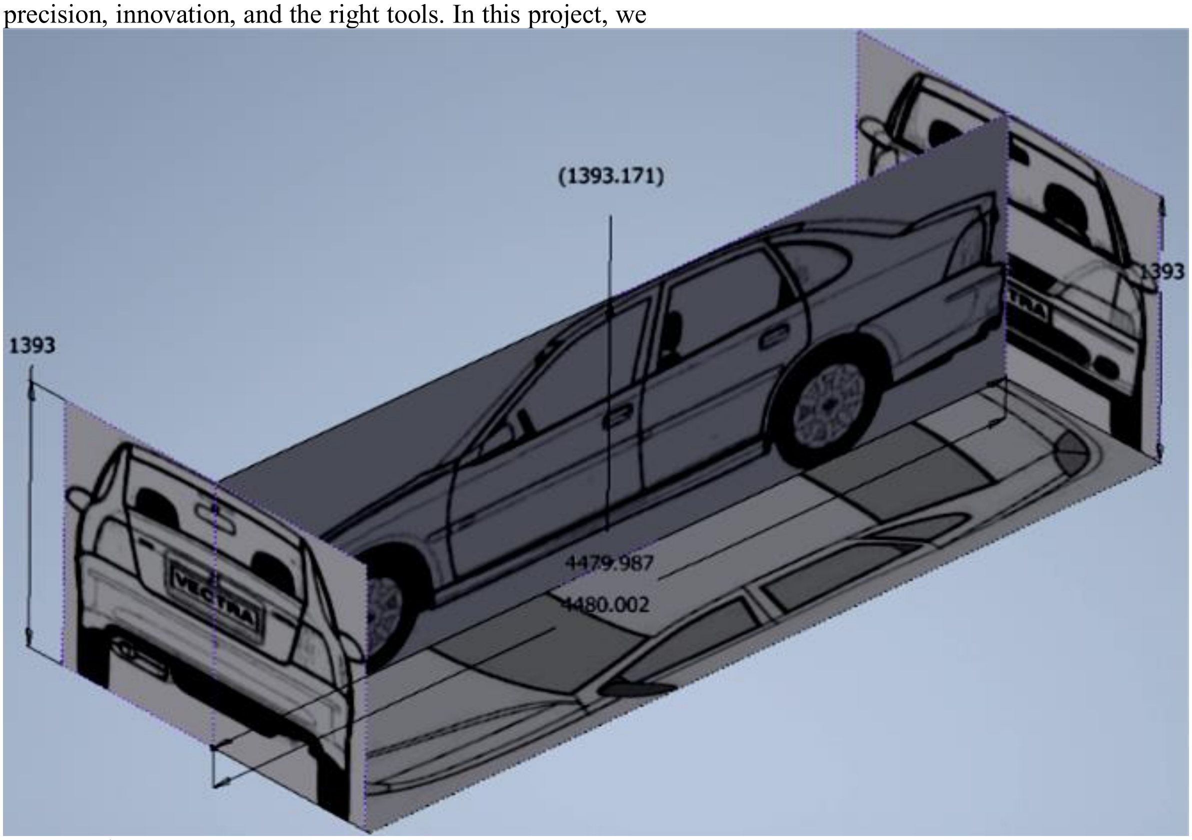


Figure 4: 1st step in creating the 1998 Opel Vectra 3D model

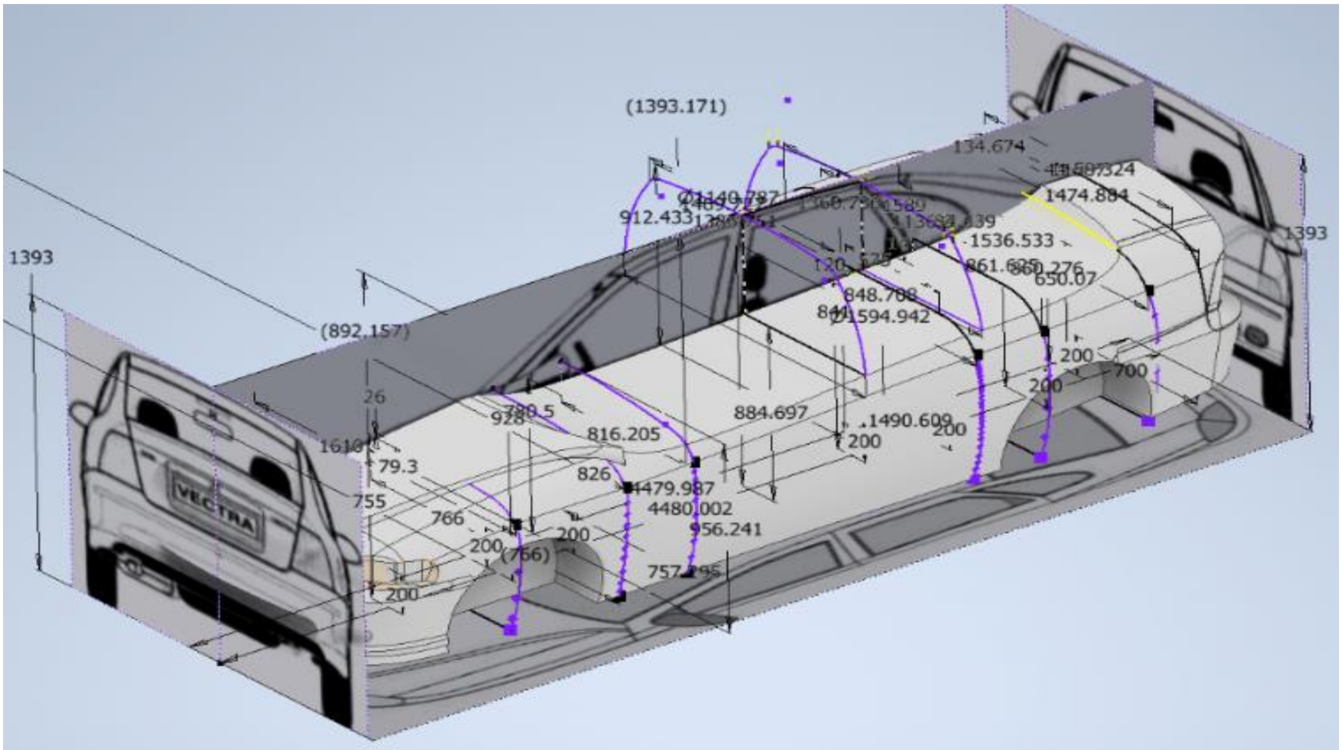


Figure 5: 2nd step in creating the 1998 Opel Vectra 3D model

Final were created using the Sweep tool by defining a window profile and sweeping it along a designated path that followed the car's frame. This allowed for accurate shaping of the window openings, maintaining both aesthetic quality and dimensional precision according to the vehicle’s design, as shown in figure. Similarly, the roof structure and the front and rear windscreen frames were modeled using the Sweep tool. By sweeping specific profiles along carefully defined paths, the curvature and alignment of these critical sections were replicated accurately, ensuring a realistic fit for the glass panels in later stages. To finalize the windscreen and roof geometry, the Extrude Cut tool was applied. Precise cuts were made into the previously created solid body to open the front and rear windscreen areas. This operation enabled the model to match the vehicle's original design intent, providing realistic apertures for glass installation. As shown in figure 7.

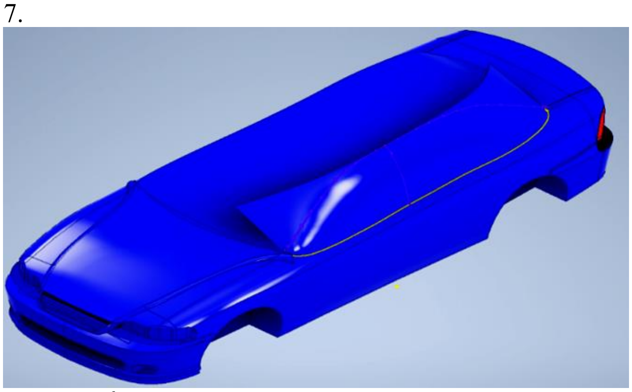


Figure 6: 3rd step in creating the 1998 Opel Vectra 3D model

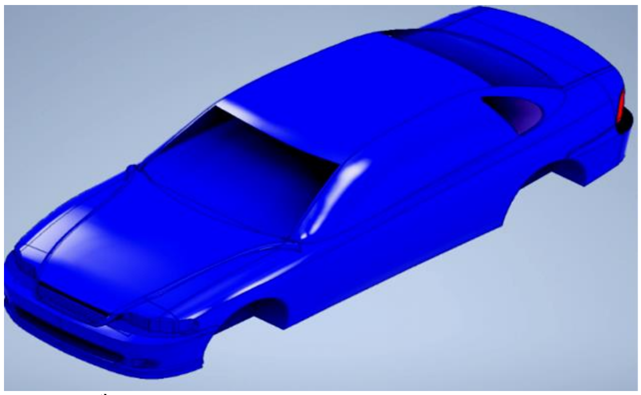
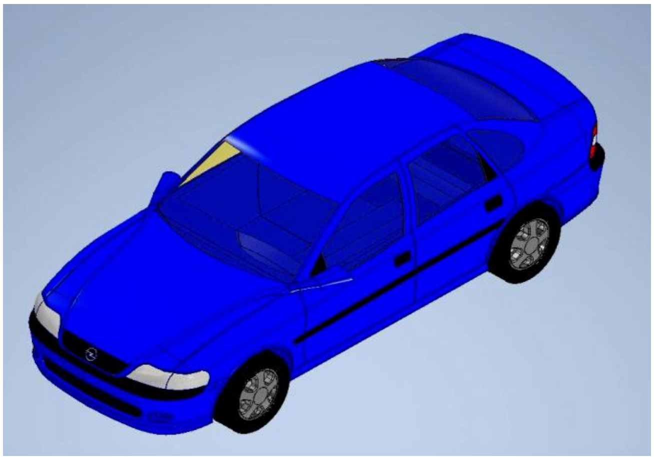


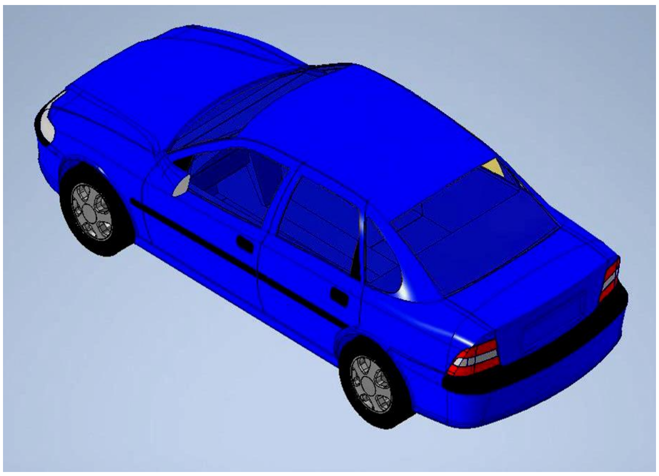
Figure 7: 4th step in creating the 1998 Opel Vectra 3D model

B. 3D Model Assembly

The 3D assembly of the modified Opel Vectra 1998 chassis was meticulously executed using Autodesk Inventor to ensure structural integrity and functional accuracy. The assembly process began with the integration of the wheels, where each component was precisely aligned using Mate and Insert constraints to replicate real-world hub-to-suspension mounting conditions and maintain bolt pattern fidelity. The suspension system, including MacPherson struts and trailing arms, was modeled with careful attention to dynamic load paths, and its performance was validated through finite element analysis (FEA) under operational loading conditions. The interior layout was assembled by parametrically placing the seats, dashboard, and controls, ensuring compliance with ergonomic standards and optimized weight distribution. To simulate mechanical behavior, kinematic joints were applied to the four doors, trunk, and hood, enabling realistic opening and closing mechanisms through hinge constraints. Throughout the assembly, collision detection was utilized to identify and resolve potential interferences, ensuring manufacturability, operational safety, and spatial compatibility. This comprehensive digital assembly accurately reflects the mechanical and functional behavior of the Opel Vectra 1998, serving as a validated foundation for subsequent performance analyses and optimization studies.



Figures 8: Final 1998 Opel Vectra 3D model front view



Figures 9: Final 1998 Opel Vectra 3D model rear view

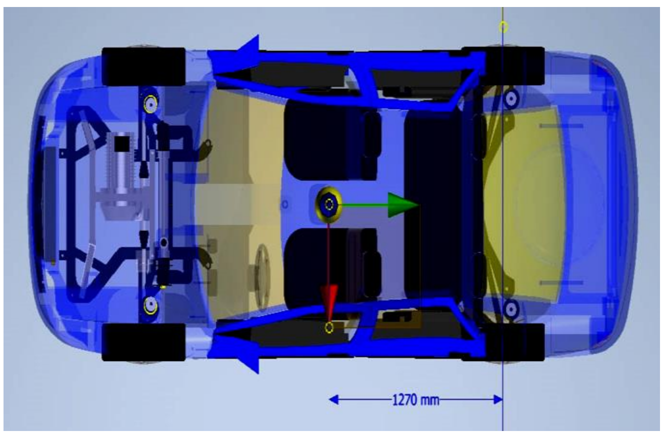
VI. Understanding Vehicle Center of Gravity

The center of gravity (CG) serves as the pivotal point where a vehicle's mass is theoretically concentrated, with its position precisely determined using a top-view schematic and fixed chassis reference point for longitudinal measurement, while vertical height was calibrated from the front axle line. In our Opel Vectra study, digital measuring tools and 3D CAD modeling captured even minor CG shifts (as small as 2mm) with high accuracy, with all fixed components (engine, suspension, fuel tank) held constant to isolate the effects of variable passenger loads. This methodological rigor proves equally critical for EV conversions, where battery packs and electric drivetrain components dramatically redistribute mass - often raising the vertical CG position compared to internal combustion vehicles. The CG's three-dimensional coordinates collectively influence key behaviors: a lower CG enhances roll resistance during cornering, while elevated positions increase rollover risks, particularly in high-clearance conversions.

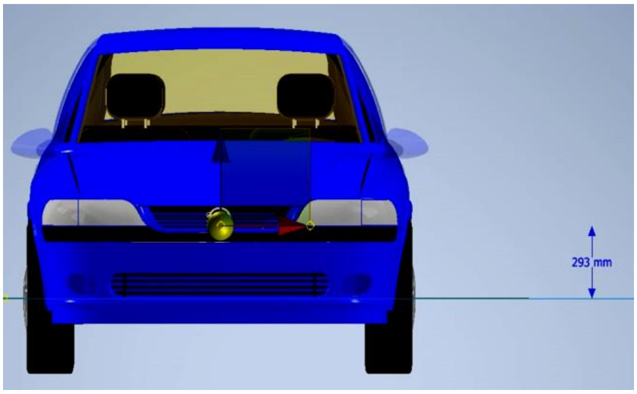
By maintaining constant base vehicle parameters and focusing solely on passenger load variations (75kg per occupant), we established clear causal relationships between mass distribution and CG movement - an approach directly applicable to EV conversion design where battery placement becomes the primary variable. The measured 15mm rearward CG shift from rear passenger loading mirrors the effects of rear-mounted EV batteries, demonstrating why conversion projects require similar precision measurement techniques. To mitigate these stability challenges, engineers employ compensatory strategies like strategic battery positioning using CAD/FEA tools, chassis reinforcement, and suspension recalibration - all validated through our case study's methodology. The Opel Vectra results prove that maintaining sub-3mm vertical CG variance during loading is achievable through low-profile component packaging, providing a benchmark for EV conversion stability standards.

A. Case 1: Vehicle Unloaded (No Passengers)

In its baseline condition, the vehicle is free of any additional human or cargo load. The CG was measured at a longitudinal position of 1270 mm from the designated reference point, and the vertical height from the front axle was 293 mm. This placement reflects the default mass distribution of the vehicle’s structural and mechanical components, such as the front-mounted engine, transmission, and supporting frame. This configuration serves as the reference for subsequent load scenarios.



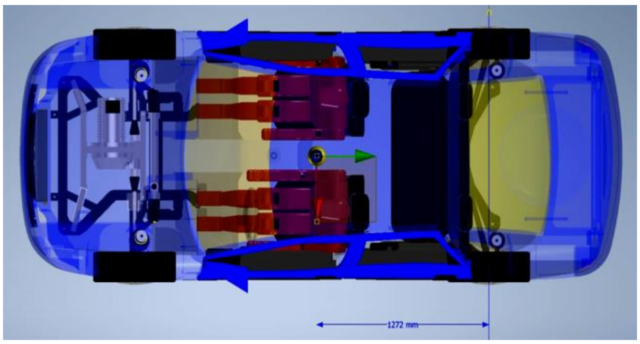
Figures 10: Unloaded Vehicle CG Measurement top view



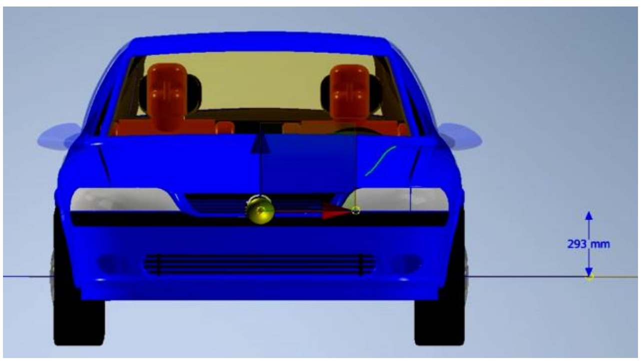
Figures 11: Unloaded Vehicle CG Measurement front view

B. Case 2: Two Front Passengers

Adding two front passengers (average 75 kg each) resulted in an approximate 8% increase in the total vehicle mass. The CG shifted slightly rearward to 1272 mm, a movement of +2 mm from the unloaded condition. The vertical CG height remained unchanged at 293 mm, indicating that the added mass was aligned vertically close to the vehicle's original CG plane, leading to a negligible vertical shift but a small longitudinal displacement.



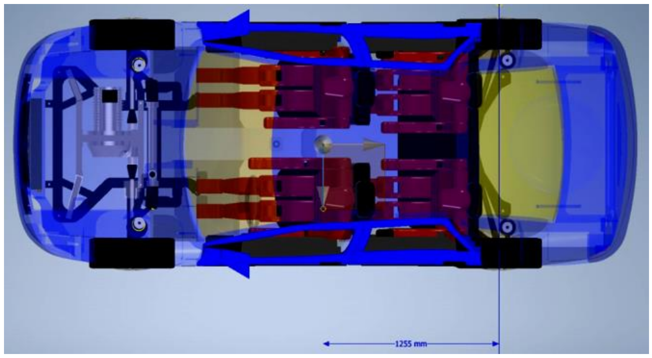
Figures 12: loaded with 2 Passengers Vehicle CG Measurement top view



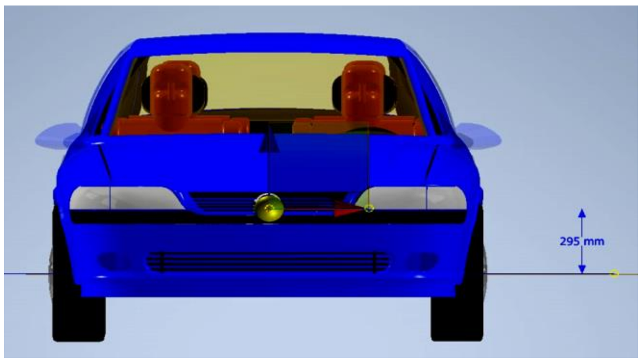
Figures 13: loaded with 2 Passengers Vehicle CG Measurement front view

C. Case 3: Four Passengers (Front and Rear)

When two additional passengers were seated in the rear, the total added mass increased to roughly 16% of the vehicle's original weight, nearing the vehicle's designed load capacity. In this case, the CG moved rearward to 1255 mm, representing a –15 mm shift compared to the unloaded state. The vertical height of the CG also increased to 295 mm, indicating a lower but more rearward distribution of mass due to the placement of passengers over the rear axle. This movement suggests a greater influence of rear-seated passengers on the vehicle's overall CG location, as their position induces increased load on the rear axle and a measurable redistribution of balance.



Figures 14: loaded with 4 Passengers Vehicle CG Measurement top view



Figures 15: loaded with 4 Passengers Vehicle CG Measurement front view

D. Comparative Table of CG Measurements

The analysis clearly demonstrates a direct relationship between occupant load distribution and the vehicle's center of gravity in both longitudinal and vertical dimensions. In the unloaded condition, the vehicle shows a balanced CG placement, reflecting an optimal design that supports predictable handling and braking characteristics. As shown in the Table 3, the addition of two front passengers causes a minimal longitudinal shift without affecting the vertical CG, suggesting that the mass addition is well-aligned with the vehicle's CG plane.

Table 3: ***Technical Specifications of Opel Vectra 1998 (ICE Configuration)***

Load Condition	Longitudinal CG (mm)	Vertical CG from Front Axle (mm)	Notes
Unloaded	1270	293	Reference condition
Two Front Passengers	1272 (+2 mm)	293	Minor longitudinal shift
Four Passengers	1255 (–15 mm)	295 (+2 mm)	Noticeable shift in both axes

However, with the rear seats occupied, the CG shifts significantly rearward and slightly upward. This is due to the passengers being seated at the far end of the chassis and at a lower level, which increases the rear axle load. Consequently, the load on the front wheels decreases, potentially reducing steering responsiveness, and increasing the risk of oversteer in sharp turns or during emergency braking. These, observations are critical in vehicle design and modification, especially when considering structural changes or conversion to electric systems, where battery placement can introduce similar shifts in CG. Thus, maintaining balance across all load states is vital to ensure consistent performance and safety.

VII. Conclusion

The switch to electric vehicle (EV) systems from gasoline-powered engines is a big step in the direction of environmentally friendly transportation. This analysis has shown that switching to electric propulsion for internal combustion engine (ICE) cars can have significant positive effects on the environment, the economy, and performance, such as lower emissions, cheaper operating costs, and increased energy efficiency. But there are drawbacks to these conversions as well, particularly regarding the initial outlay of funds, technical difficulty, battery integration, and regulatory compliance. Despite these obstacles, electric conversions are becoming more practical and appealing, especially for older cars, fleet applications, or specialized auto enthusiasts, thanks to developments in battery technology, the expanding supply of EV components, and the increased emphasis on decarbonization worldwide. Converting gasoline-powered vehicles is ultimately a feasible and significant step in the larger framework of sustainable mobility and circular economy practices, even though it may not be the best option for mass electrification just now.

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