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Review of Engineering Design of Electric Vehicles

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ABSTRACT

The global transition toward sustainable transportation has increased the adoption of electric vehicles (EVs) to reduce greenhouse gas emissions and lessen the environmental impact of traditional internal combustion engine (ICE) vehicles. This project explores the design, performance, and challenges associated with electric cars, particularly focusing on vital components such as battery technology, charging infrastructure, energy efficiency, and suspension systems. Using Autodesk Inventor for 3D modeling and ANSYS for simulation and analysis, the project thoroughly examines the mechanical and thermal performance of the vehicle. The suspension system integrates a double wishbone design, optimized for race car dynamics, to enhance handling, stability, and performance. The research also evaluates recent advancements in lithium-ion battery technology, which have greatly improved energy density and driving range in modern EVs. Additionally, the project looks into the difficulties of building extensive charging networks and explores the economic, environmental, and social impacts of transitioning to electric vehicle infrastructure. Consumer perceptions and the role of government policies and incentives in promoting EV adoption are also discussed. By analyzing the current state of EV technology and identifying obstacles to mass adoption, this project aims to offer valuable insights into the future of sustainable transportation. The findings highlight the need for continued innovation, strategic investments, and public-private partnerships to expedite the shift to an electrified automotive industry.

1. Introduction

By providing cleaner, more environmentally friendly substitutes for traditional internal combustion engine vehicles, electric vehicles (EVs) are revolutionizing the transportation industry. The potential of EVs to lower greenhouse gas emissions, energy dependence, and urban air pollution has led to a steady increase in their adoption, according to Muratori et al. (2021) [1]. Global EV adoption trends from 2010 to 2020 are shown in Fig. 1 [1].

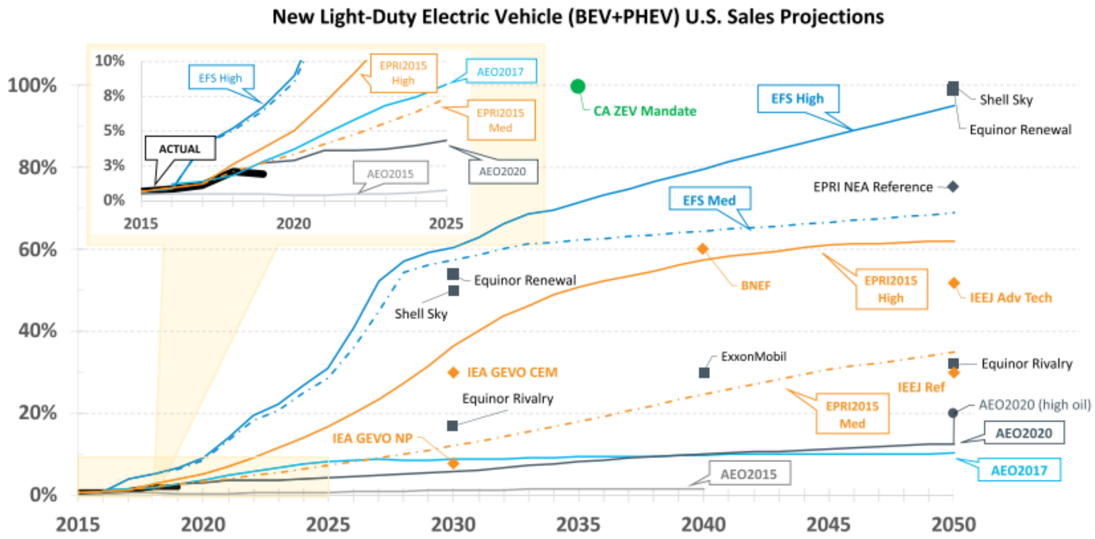


Fig. 1: Global EV adoption trends from 2010 to 2020 [1].

The development of batteries is one of the main factors propelling the growth of EVs. Lithium-ion batteries have emerged as the preferred option for EVs due to their higher energy density, longer life cycles, and enhanced safety when compared to previous battery technologies, according to Scrosati and Garche (2010) [2]. The evolution of battery energy densities and their effects on vehicle range are depicted in Fig. 2 [2].

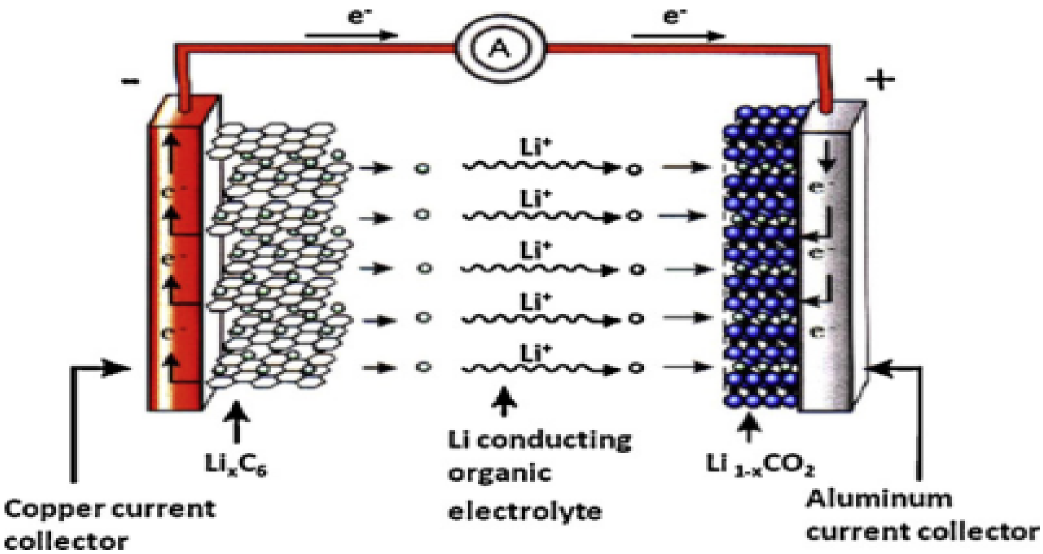


Fig. 2: The evolution of battery energy densities and their effects on vehicle range [2].

Nevertheless, there are still certain obstacles to broad adoption in spite of these developments. According to Noel and Sovacool (2016) [3], problems like range anxiety and inadequate charging infrastructure still affect how the general public views EVs. which illustrates the variation in the accessibility of charging infrastructure across various regions, makes this clear. According to a comparative lifecycle analysis of conventional and electric vehicles from an environmental standpoint, Hawkins et al. (2013) [4] discovered that although EVs have higher manufacturing emissions (primarily from batteries), they have substantially lower operational emissions over the course of their lifetime. A graphical comparison of lifecycle emissions for different vehicle types is shown in Fig. 3 [4].

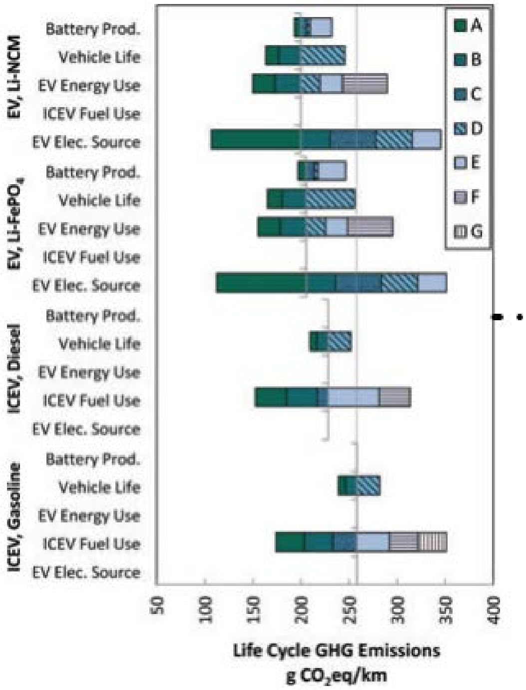


Fig 3. A graphical comparison of lifecycle emissions for different vehicle types

Addressing these issues through innovative policy, advancements in technology, and the development of infrastructure is essential to the future of EVs. These initiatives will open the door for a cleaner and more sustainable transportation industry.

2. Chassis Design

The chassis, the vehicle's core framework, is crucial for structural integrity, safety, and performance. Advancements in materials and manufacturing have led to diverse chassis designs, including lattice, space frame, and monocoque structures. Monocoque designs, known for their integrated structure, are standard in modern passenger cars, offering a balance of rigidity and lightweight design. Space frames, built from interconnected beams or tubes, provide adaptability and modularity, making them popular for racing and high-performance vehicles. Lattice structures, a newer concept, utilize intricate geometries for maximum material efficiency and performance, but face scalability and manufacturing challenges. This paper explores the engineering principles, historical evolution, and comparative analysis of these structural designs, aiming to inspire innovation in automotive engineering and lay the foundation for future hybrid and next-generation chassis systems.

2.1. Monocoque Chassis

In 2013, Eurenius et al. [5] argued that weight and severity are the two pivotal design rudiments for a race auto's lattice. Race buses generally use one of two lattice designs, as seen in Fig. 4, space frame or monocoque.

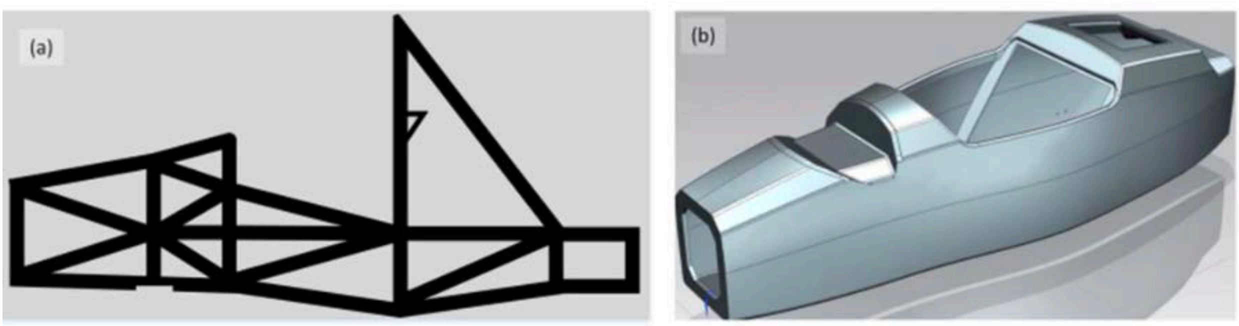


Fig. 4. Two typical chassis designs: space frame (a) and monocoque (b) [5].

The space frame chassis is composed of many shaped structural metal pipes, usually constructed of steel, to provide a strong construction. A monocoque chassis combines the body and chassis to form a composite design with enhanced rigidity and weight benefit. The stress that a vehicle produces while in motion is distributed throughout the frame of a monocoque chassis. In 2015, Christensen, John [6] The following generalities were developed for the coming lattice The frame of space frame monocoques can be classified as full, semi-monocoque, or mongrel (top half monocoque from frontal bulkhead to hinder roll circle).

Fig. 5. Semi Monocoque Concept [6]

A semi-monocoque the semi-monocoque conception has been employed by FSAE brigades as a precursor to full monocoque. The space frame lattice, which frequently lasts numerous times, comprises several structured structural essence pipes to give a strong structure. A SolidWorks model of this is shown in Fig. 5.

Fully monocoque. Some brigades decide to move forward with a full monocoque construction after trying a semi-monocoque. A SolidWorks model of the whole monocoque is shown in Fig. 6. Sword front and hinder roll loops are needed per FSAE conditions. Ways and Physical Torsion Testing Carriage Torsion testing on a lattice was the main testing system. as depicted in Fig. 7.

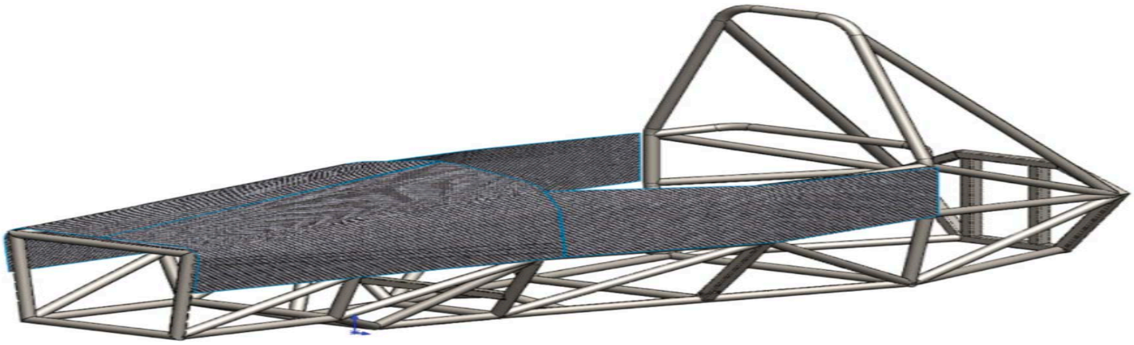


Fig. 6. Full Monocoque Concept [6].

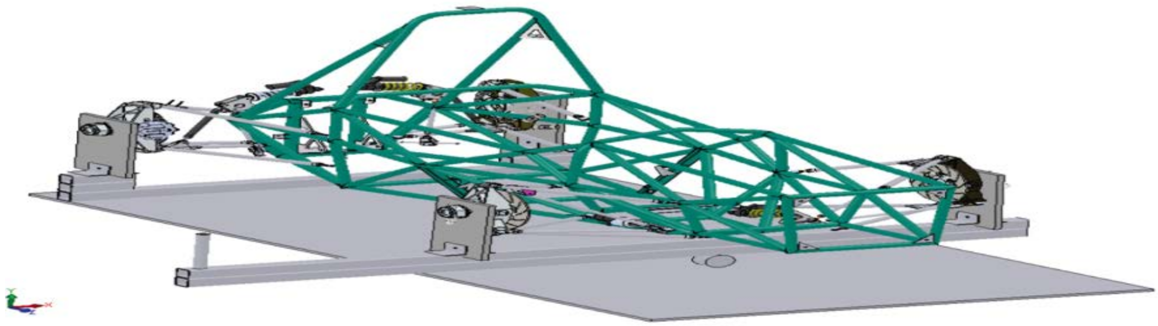


Fig. 7. Assembly modeling for torsion testing on Solid works [6].

Chassis Torsional FEAs were used to predict the chassis flexing during physical testing. As shown in Fig. 8,9.

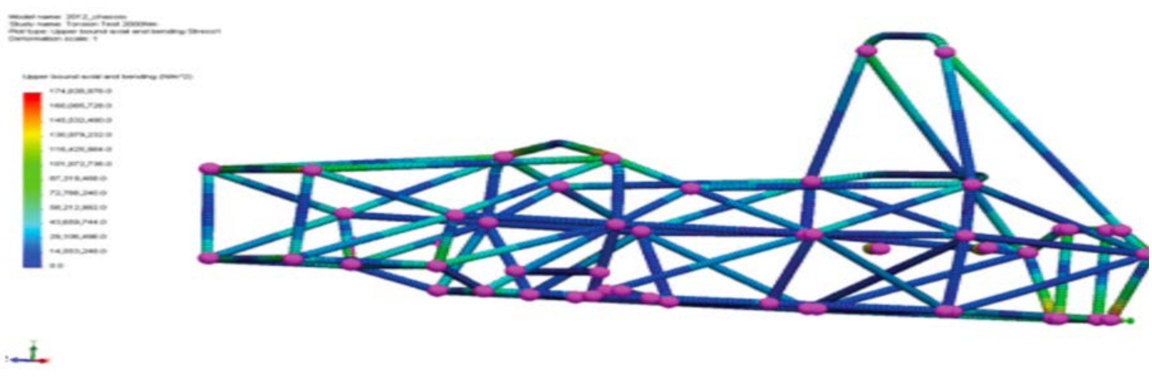


Fig. 8. Tress analysis for a chassis (deformation scale = 1) [6].

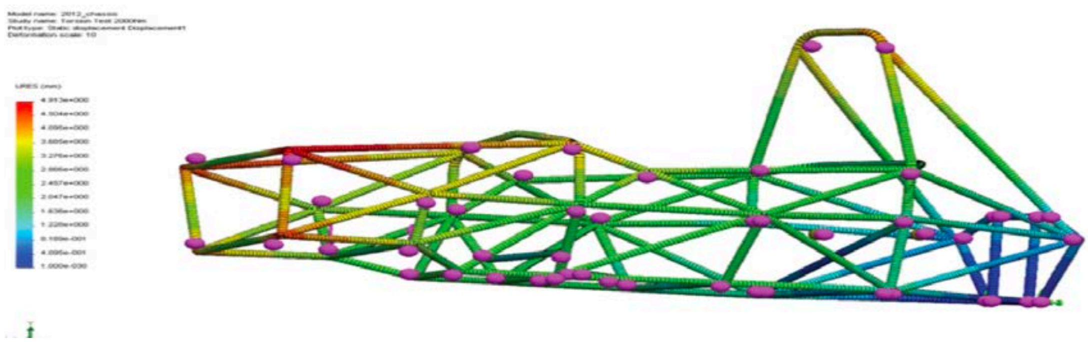


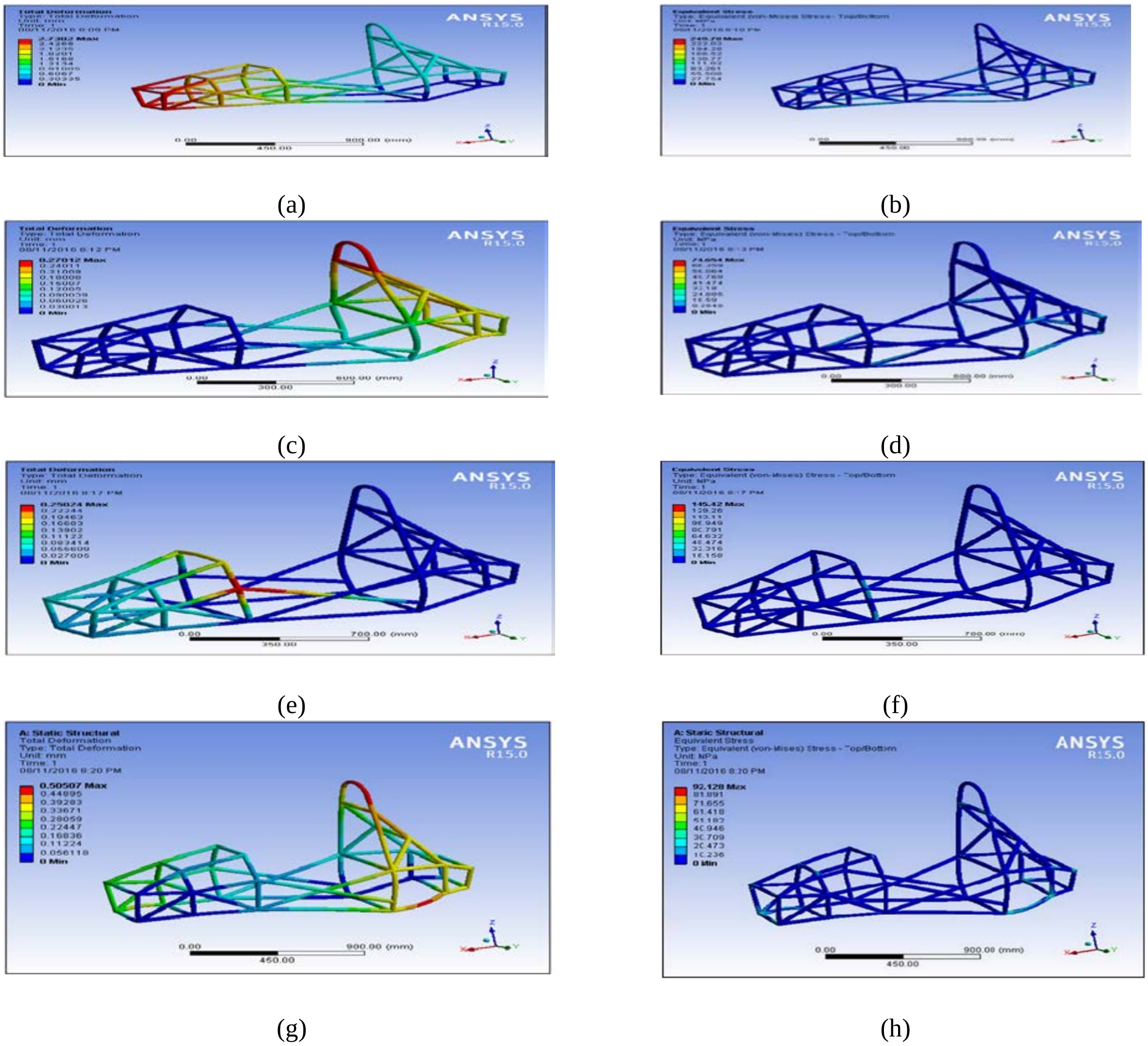
Fig. 9. The displacement plot of the chassis when a torque of 2000 Nm is applied [6].

2.2. Space Frame Chassis

In 2020, Agarwal et al. highlighted that a space frame chassis is a structural framework composed of interconnected tubes designed to provide maximum strength and rigidity while minimizing weight. This design is especially advantageous for racing cars because of its high stiffness-to-weight ratio. It is crucial to balance the chassis's rigidity and weight while also ensuring the driver's safety [7].

In 2016, Tyagi noted that a space frame chassis is one of the most common designs used in automobile applications. Its popularity stems from the design flexibility it offers. This type of chassis is based on the principles of truss structures, which are triangular frameworks designed to handle loads either in tension or compression. As a result, a space frame chassis incorporates multiple trusses, making it exceptionally strong when subjected to various forces. Many automotive specialists prefer using space frame chassis in high-performance racing vehicles [8].

For the front impact analysis, they simulated a car collision at a speed of 27.78 m/s with a rigid barrier, which generated an impact force of 34,712.5 N. This resulted in observable deformation and von Mises stress patterns, as shown in Figures 10 (a) and (b). In the rear impact analysis, a force of 10 kN was applied to the rear end of the chassis to simulate a 4G impact, while the front end was constrained. The deformation and von Mises stress for this scenario are illustrated in Figures 10 (c) and (d). For the side impact analysis, a force of 7,500 N was applied to the side of the chassis to simulate a 3G impact, with the opposite side constrained. The resulting deformation and von Mises stress are presented in Figures 10 (e) and (f) [9]. Fig. 10 (g) and (h) illustrate the deformation and von-Mises stress patterns observed in this test.



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 10. (a) Deformation for front impact, (b) Von-mises stress for front impact, (c) Deformation for rear impact, (d) Von-mises stress for rear impact, (e) Deformation for side impact, (f) Von-mises stress for side impact, (g) Deformation for torsional test, and (h) Von-mises stress for torsional stress [9]

2.3. Lattice Frame Structure

The lattice frame, also known as a space frame, has become a fundamental component of racing car design because of its ability to balance performance, weight, and strength. According to Agarwal et al. (2020) [5], this design is a triangular arrangement of interconnected tubular bars. Thanks to this arrangement, the structure can distribute forces

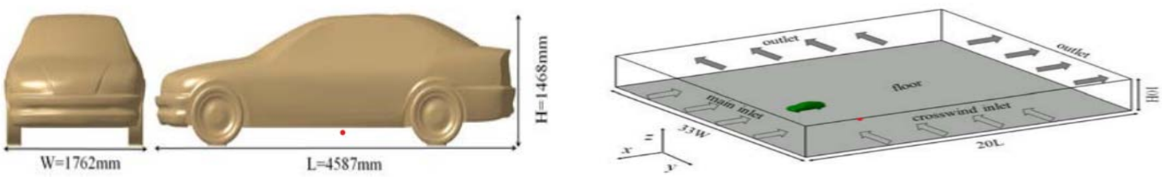
uniformly, guaranteeing minimal deformation and maximum rigidity. Because every gram saved adds to increased speed and agility in racing applications, its high strength-to-weight ratio is crucial.
Lattice frames have evolved because they may be used to meet a wide range of engineering needs, from crash safety to high-speed stability. As Tyagi (2016) points out, they have come to represent high-performance motorsport, especially in Formula SAE and comparable formats [6].

3. Aerodynamics

Aerodynamic performance is crucial for vehicle design since it affects a vehicle's stability, efficiency, and driving dynamics. This paper aims to combine various research findings and highlight advancements in aerodynamic studies and the application of computational fluid dynamics (CFD) within the auto industry.

In 2018, Wang et al. conducted a study on the aerodynamic characteristics of racing cars using wind tunnels and CFD simulations. They analyzed six forces: drag force, lift force, side force, rolling moment, pitching moment, and yawing moment. An aerodynamic model was developed to thoroughly understand these forces acting on the car based on specific parameters. The results from wind tunnel experiments were comparable to CFD analyses, with an average deviation of 4% or less, which validated the accuracy of the simulation model.

In 2017, Huang et al. highlighted the significant impact of unsteady aerodynamic forces on the dynamics and stability of passenger cars in crosswind conditions. They utilized a fully coupled simulation method that provides a more accurate representation of real driving situations compared to quasi-steady and one-way approaches. This underscores the importance of detailed analysis in vehicle design and safety assessments. The study focused on a passenger car model, as illustrated in Fig. 11(a). The passenger car was placed on the floor in the computational domain, as shown in Fig. 11(b). With a blockage ratio of approximately 0.25%, this configuration falls within the accepted limit of 5% for vehicle aerodynamic simulation. At the main inlet boundary, airflow velocity was set to -30 m/s, representing the speed of the passenger car.



(a) (b)

Fig. 11. (a) Passenger car model, and (b) Computation domain [13]

4. Dynamics

In April 2017, Dishant, Singh, and Sharma summarized the functioning of suspension systems and identified three main types: 1) dependent suspension, 2) independent suspension, and 3) semi-independent suspension. These types are widely used in the automotive industry, particularly in active suspension systems, MacPherson strut suspension, double wishbone suspension, and trailing arms.

The suspension system works by using control arms or links that allow the wheels to move independently of the vehicle body. This design helps isolate the vehicle from road bumps. The springs are responsible for manipulating and reducing the frequency of road disturbances, aiming to improve the ride quality. They also provide damping through friction at the spring ends and the seat. Additionally, the damper dissipates the energy from dynamic loads caused by bumps in the street.

Together, these components work to mitigate the effects of road shocks on passengers and enhance the stability and handling of the car, as illustrated in Fig. 12.

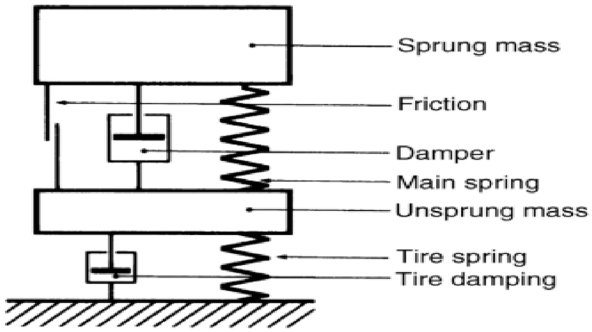


Fig. 12. Quarter car model [16]

In their 2020 study, Mortazavizadeh et al. [22] predicted that the future of steering technology will be characterized by steering by wire (SBW), a system that eliminates the mechanical connection between the steering wheel and the tires. The SBW system consists of two primary subsystems: the hardware (HW) and the rear wheel (RW).

The HW module is responsible for receiving commands from the driver and converting the desired steering angle into an electronic signal through sensors located on the motor shaft of the HW. This signal is then sent to the RW subsystem, which adjusts the angle of the tires accordingly. By removing the mechanical linkage, SBW offers several advantages, including improved design flexibility, reduced weight, and savings in space and cost as shown in Fig. 13.

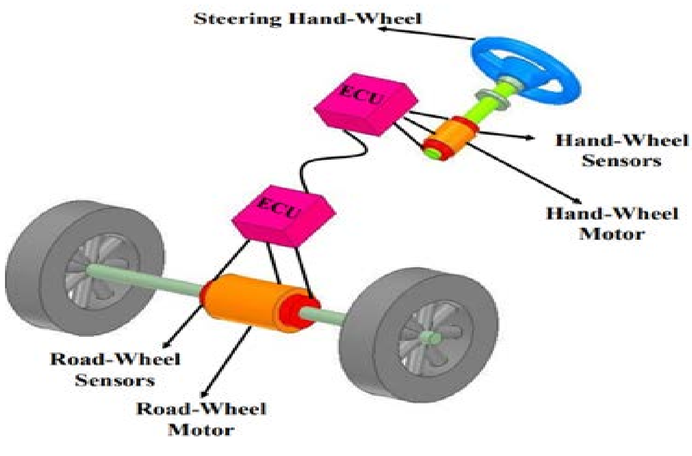


Fig. 13. Steering by wire [22]

In March 2013, Sharma and Marwah summarized the types of braking systems. The current trends in braking systems include disc brakes and drum brakes. Drum brakes are generally less expensive, but they tend to wear out more quickly and incur higher maintenance costs, making them less economical and efficient overall. In contrast, disc brakes are considered a premium option due to their higher cost and superior performance. Drum brakes operate using friction generated by shoes or pads pressing against a rotating drum-shaped component known as the brake drum. They were invented in 1902 by Louis Renault and initially used woven asbestos lining. Throughout the 1960s and 1970s, disc brakes gradually replaced drum brakes on the front wheels of cars. Today, most vehicles are equipped with disc brakes on the front wheels, and many also use them on all wheels as shown in Fig. 14. Drum brakes are still commonly employed for handbrakes, as designing a disc brake that can effectively hold a parked car poses challenges. Additionally, the United States Federal Government began regulating asbestos production, which prompted the transition to non-asbestos linings in braking systems.

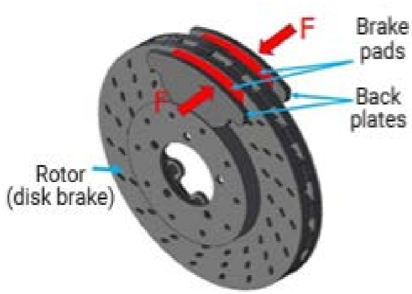


Fig. 14. Contact of pads with Disc [28]

Brake pads are categorized into various types based on their intended use and the materials they are made from. They are designed for different vehicles, including standard road cars, high-speed vehicles, trucks, buses, and racing cars. Design features may include single-layer, multilayer, or additional layers. The composition of the friction material can be semi-metallic, non-asbestos organic (NAO), or ceramic. Table 1 presents a detailed breakdown of brake pad composition [28].

Table 1: Material of pads and it's properties [28]

NAO (non-asbestos organic)	The friction linings are made from a mixture of organic fibres such as glass fibre, Kevlar, aramid, carbon fibre, and high-temperature resins. The metal content in their composition does not exceed 20%.	J less noise and softer braking; J less wear on the brake discs; J more environmentally friendly as they do not contain asbestos.	J shorter service life than metal pads; J less effective at hot temperatures; J used for small passenger cars
Ceramic	The friction layer of this type consists of ceramic fibres bonded with special resins, sometimes with a small amount of non-ferrous metals	J long service life; J stable performance even at hot temperatures; J reduce the amount of brake dust.	J more expensive to produce and usually have a higher price; J low initial coefficient of friction.

Source: compiled by the author of this study based on V.I. Mohyla & M.H. Aldokimov (2018), A. Sinha *et al.* (2020)

5. Conclusion

The engineering design of electric vehicles (EVs) has been shown in this study to have notable developments and difficulties. Reducing environmental effects, particularly with regard to greenhouse gas emissions, depends on the switch to electric cars. By investigating important elements such battery technology, suspension systems, chassis design, and aerodynamics, we have revealed the continuous advancements and innovations forming the future of EVs. Developments in lithium-ion battery technology have significantly increased energy density and vehicle range, hence enabling electric automobiles for daily usage. Still in the way of mainstream EV adoption, though, are issues like range anxiety and inadequate charging infrastructure. This study also emphasizes the vital need of government policies, consumer knowledge, and technical investments in overcoming these challenges. Improving the performance, safety, and comfort of EVs depends on the engineering ideas under discussion, which include different chassis configurations and suspension systems. Future research and development initiatives should concentrate on enhancing the efficiency of energy storage systems, fine-tuning these designs, and extending charging infrastructure. Realizing the full environmental advantages of EVs also depends on the inclusion of sustainable practices in car manufacture and the lowering of lifetime emissions. Ultimately, even although the electric vehicle sector is developing quickly, more creativity and intersectoral cooperation are still required to hasten the adoption of electric cars and create a more sustainable, greener transportation future.

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