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Frontal Crash

Automotive Chassis Systems (ACHA5013)

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1. Introduction

The automobile is one of the most sophisticated engineering inventions known to mankind. From the first automobile powered by steam engine in 1885 by Karl Benz (Mercedes Benz Group 2023) to today's modern vehicles, the automotive industry has ever been at this high level in history. Since the first ever vehicle, vehicles have become our day-to-day transportation and have affected our lives greatly, not only by helping to deliver us from point to point but also by the great safety features of the structure preventing precious lives. The car manufacturers today, constantly competing on the market with other brands to build a vehicle that fills all the requirements and regulations set by the heads to meet the customer's expectations. The car designs become more complex due to the factors such as aerodynamics, chassis structures, crashworthiness, stiffness and bendings. The report will explore the research of how vehicle structures have developed and the impact of manufacturing and material development, as well as the impact of regulations. The second part of the report will cover the comparison of the chosen vehicles and its maximum forces on the frontal crash pulse.

2. Historical Development of Vehicle Structures

Since the advent of the automobile in the early 1900s, automotive chassis structures have evolved greatly. In the beginning, vehicles featured a traditional ladder frame structure that provided a strong and durable base for the body panels. This basic structure remained largely unchanged for nearly 80 years until manufacturers began to introduce monocoque chassis designs in the 1950s. The monocoque chassis design was first used in Formula One in the 1960s by Lotus (CNBC, 2023). This approach replaced the frame with a single metal unit which had increased stiffness, safety, and rigidity while also saving weight and freeing up more interior space. This design allowed automakers to provide the most economical and reliable vehicles possible. However, over time, improvements in manufacturing and materials science allowed automakers to develop more advanced chassis structures that offer even greater rigidity, comfort, and efficiency than the old ladder frame. Today's modern cars feature unitary or unibody construction. This type of chassis involves forming the frame out of one piece, creating an integrated structural shell. Compared to older designs, this type of frame is stronger, lighter-weight, and more efficient. These advances include components such as four-wheel independent suspension, shock absorbers, and stiffening elements such as hydroforming or ultrahigh strength steel to increase overall rigidity. The electric car structure has been gaining popularity over the last decade and electric vehicles has seen yet another evolution in automotive chassis structures. In these cars, motors are used instead of engines and there is no need for a conventional transmission system since the power source is already located within the car's wheels. This type of vehicle design often features shorter wheelbases than its petrol counterparts in order to create more interior space without sacrificing too much stability. Additionally, the battery packs can be placed in different locations depending on vehicle specifications to provide greater levels of flexibility when designing a chassis. Internal combustion engines tend to take up huge amounts of space compared to its rival EVs, it's because of their electric motors. The electric motors are much smaller and don't need any oil to lubricate the engine unlike ICE. Most EVs have extra storage space under the hood in the front and the same space as normal vehicles in the trunk, which is a great advantage. As an increasing number of alternatives to internal combustion engine vehicles emerge, the chassis and structures of cars are concurrently undergoing evolution.

2.1 Vehicle structure types

The chassis structure types below are the most commonly used in the mass production vehicles on the road.

2.1.1 Unibody chassis

A unibody construction is made up of several components that are joined, bonded, molded, or otherwise connected (Markus, 2020). This structure was initially utilized on the Lancia Lambda "torpedo-bodied" in 1922–1931, and it benefited in lowering the car's height and weight. Most contemporary SUVs, sedans, and crossovers have unibody chassis; some even employ the Airflow principle, which involves welding what almost seems to be a whole frame below to improve rigidity, and strength, and reduce harshness.



Figure 2.1.1.1 Unibody structure

2.1.2 Monocoque chassis

Monocoque means "single shell" or "single hull" in French. Monocoque structures feature structural skin that can withstand tension and compression loads, just like the exoskeletons of insects. It was a popular construction technique for ships and later airplanes in the beginning. It is a shell that encircles the vehicle and is constructed from both chassis in one piece. Even though real monocoque structures were uncommon in everyday automobiles at the time, the racing industry has embraced the idea. In 1962, aluminum was used for the first time in the Lotus 25 Formula 1 race car's body and chassis. McLaren created the now-standard carbon fiber-reinforced composite monocoque racing vehicle frame with the 1981 MP4/1.



Figure 2.1.2.1 Monocoque chassis vehicle

2.1.3 Tubular chassis

The tubular frame chassis is commonly used in auto race industry. Because they were more robust and three-dimensional compared to ladder chassis, they were an improvement. Behind the doors, they used a solid framework that increased their overall strength. Racing vehicles have no interiors because they are too heavy; instead, the car is covered and made of aluminum or tick tube rods. This chassis offers the advantages of being lighter, and stronger than a standard monocoque construction and having no interior fittings. One of the main drawbacks of tubular chassis is that they are not practical for daily driving (Harsh, 2021).

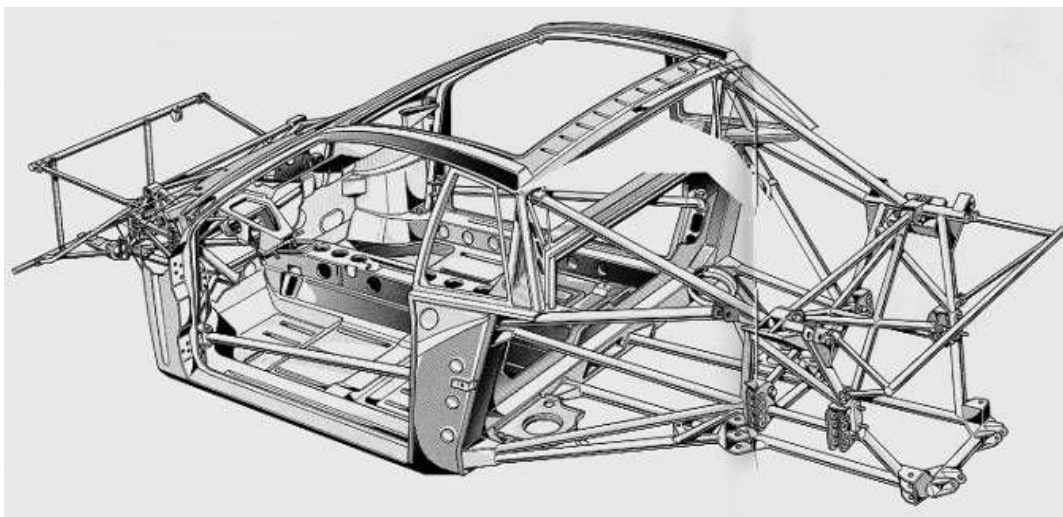


Figure 2.1.3.1 Tubular chassis

2.1.4 Ladder frame chassis

In general, the ladder frame chassis can be found in heavy duty vehicles such as, 4x4s, pickup trucks, construction vehicles and SUVs. Since the vehicle's body or cabin is placed on the frames, independent axles have greater travel, resulting in greater chassis articulation compared to other chassis configurations. These vehicles typically have a four-wheel drive and are well-known for their excellent off-road capabilities. The ladder frame chassis provides the following advantages:

- The vehicle's body can be lifted out and a different body can be fitted.
- The suspension can be easily adjusted.
- These vehicles have a great flexibility and remarkable at offroading.
- It is quieter in the interior as the chassis acts as insulation for the body.
- Easy to change components.
- Highly practical compared to other types of chassis.
- They are usually made from steel and are exceptionally strong (Harsh, 2021).

The disadvantages of the ladder frame chassis are;

- Poor handling due to the heavyweight.
- High ground clearance and an elevated center of gravity contribute to reduced stability.
- Usually has a greater cost associated with it.
- Usually has a bigger body, which increases drag.



Figure 2.1.4.1 Ladder frame chassis

2.1.5 EV chassis

The chassis of electric vehicles are different from those of conventional vehicles, necessitating careful battery placement for enhanced handling and stability. These building types improve energy efficiency without sacrificing performance or safety. Materials like carbon-fiber-reinforced plastic are used by engineers to reduce noise, vibration, and harshness (NVH) and increase efficiency. Electric cars have several benefits: they are practical, quiet, emit no pollutants, require less maintenance, accelerate more quickly, and have a simpler chassis to build. However, the cost of owning an electric car can be high, getting replacement components can be difficult due to high servicing expenses, the chassis is often heavy, there is a risk of fire tied to the battery, and charging the batteries can take several hours. Despite these difficulties, the structure of the automobile has advanced greatly, changing everyday transportation from the days of ladder frames to modern unibody electric vehicle designs.



Figure 2.1.5.1 EV chassis

2.2 Torsion and Bending

In the early stages of vehicle development, emphasis was placed on ensuring structural integrity against torsional and bending forces. The prevalent chassis design during this era was typically a straightforward ladder frame. Continuous efforts were undertaken to advance these structures, aiming to improve rigidity while simultaneously reducing overall weight.

2.3 Aerodynamics

The recognition of aerodynamics as a pivotal element in vehicle design emerged over time. The integration of streamlined shapes aimed at minimizing drag and enhancing fuel efficiency significantly impacted structural decisions. This shift toward aerodynamic considerations spurred the development of more intricate monocoque structures, seamlessly integrating body panels into the overall design.

2.4 Crash Requirements & Safety

Over the last century, there have been significant advancements in both durability and safety in car structural development. Traditionally, automobiles had a steel chassis structure that was held up by wheels and a separate suspension system that was thought to be strong enough for passenger cars. High-strength steel alloys were used in frames as a result of technological advancements, which improved crash protection. Chassis structures were further improved by computer-aided design (CAD), allowing for more equal and efficient absorption of impact forces. National regulatory authorities have set a wide range of safety criteria that are included in crash regulations. These standards include requirements for side-impact protection, head restraints, child restraints, bumper height, seatbelts and airbags, and more. By adhering to these standards, automakers ensure maximum protection for occupants in case of an accident, making the integration of crash requirements into the design process a cornerstone in building vehicles with enhanced crashworthiness. Through this dedication, the risk of injury from traffic accidents is greatly decreased and occupant safety is improved. The vehicle's ability to keep its occupants from injuries in the event of an accident is a critical component of crashworthiness. Crucial roles are played by design considerations for torsion, bending, aerodynamics, and crash criteria. While vehicle components must be made strong and flexible to absorb energy, torsional rigidity helps prevent twisting during accidents. Because of the aerodynamic design, there is less drag during crashes, and the regulatory bodies' strict implementation of crash regulations ensures that the occupants are protected to a minimum. Moreover, recent trends involve the utilization of aluminum or composite materials in car bodies, reducing overall vehicle weight without compromising strength, thereby enhancing fuel efficiency and curbing emissions. In the realm of electric cars, with their heavy battery packs, specialized chassis designs are necessary, incorporating reinforced joints and higher-strength materials to handle the additional load while maintaining performance. These ongoing advancements reflect a commitment to not only historical safety standards but also to contemporary challenges and sustainability goals in the automotive industry.

3. Manufacturing and Material Development

In the realm of automotive evolution, the manufacturing processes and materials utilized have undergone transformative developments. Traditionally, vehicles were constructed with a focus on robustness and structural integrity, primarily utilizing steel in the manufacturing of chassis frames. This conventional approach, while sturdy, often resulted in heavier vehicles. However, with technological advancements, particularly in manufacturing techniques and material science, there has been a paradigm shift. Modern automotive manufacturing increasingly integrates high strength steel alloys, aluminum, and composite materials. These advanced materials not only contribute to enhanced crash protection but also facilitate the construction of lighter yet robust structures, addressing concerns related to fuel efficiency and emissions. Furthermore, the advent of computer-aided design (CAD) has revolutionized the manufacturing process, allowing for more precise and sophisticated vehicle structures. CAD facilitates the optimization of components for strength, weight, and overall performance, leading to more efficient and safer automobiles. In recent years, the automotive industry has explored innovative manufacturing methods such as 3D printing and advanced robotics, further pushing the boundaries of what is possible in creating intricate and precisely engineered vehicle components.

4. Regulations and Consumer Driven Testing

Regulations, alongside consumer-driven testing like EuroNCAP & ANCAP, significantly influence the automotive industry and ensures baseline safety but propels the automotive industry towards innovation and consumer centric development.

1. Safety standards:

- Regulations set by authorities and organizations establish benchmarks for safety features, driving manufacturers to enhance vehicle safety beyond minimum requirements.

2. Consumer confidence:

- Stringent regulations and transparent safety ratings from EuroNCAP & ANCAP build consumer confidence, emphasizing the importance of safety in vehicle choices.

3. Technology advancements:

- Mandates for advanced safety technologies, reinforced by EuroNCAP & ANCAP assessments, stimulate innovation, pushing the adoption and improvement of cutting-edge safety features.

4. Market Competition:

- Compliance with regulations and high safety ratings from consumer testing contribute to a competitive market, compelling manufacturers to prioritize safety for better market positioning.

5. Continuous Improvement:

- Evolving regulations and updated testing methodologies from EuroNCAP foster a culture of continuous improvement, driving research and development for safer and more sustainable vehicles.

5. Comparison with Frontal Crash Forces

The vehicle I have chosen is the 2002 Ford Escape XLS. It is because the vehicle is commonly used in Mongolia as it has a great clearance and 4-wheel drive. I have chosen the rocker panel as it has both rotation and translation fixed ends. The pictures below demonstrate the calculations of the buckling load.

$k = 0.5$ Effective length factor



Euler's buckling equation

$$P_{cr} = \frac{\pi^2 EI}{(kL)^2}$$

- P_{cr} = is the critical buckling load
- E = modulus of elasticity
- I = moment of inertia
- k = effective length factor
- L = length of the column.

To calculate the moment of inertia for the rectangular cross section, the following equation is used.

$$I = \frac{1}{12} b \cdot h^3$$

b = base
 h = height

~~$I = \frac{1}{12} 191 \cdot 178^3 = 10.5 \times 10^{-5} \text{ m}^4$~~

$$I = \frac{1}{12} 191 \cdot 178^3 = 8.978 \times 10^{-5} \text{ m}^4$$

Using Euler's buckling load equation to find P_{cr} .

$$P_{cr} = 22618 \text{ kN} = \text{The expected force expected to buckle.}$$

$$\frac{\text{Max (g)}}{\text{Gross weight}} \times \text{Gross weight}$$

2002 Ford Escape XLS

$$-18g \times 2054 \text{ kg} = -36,972 \times 10^4 \text{ N}$$

$$-17g \times 2200 \text{ kg} = -3.74 \times 10^4 \text{ N}$$

1999 Isuzu Rodeo.

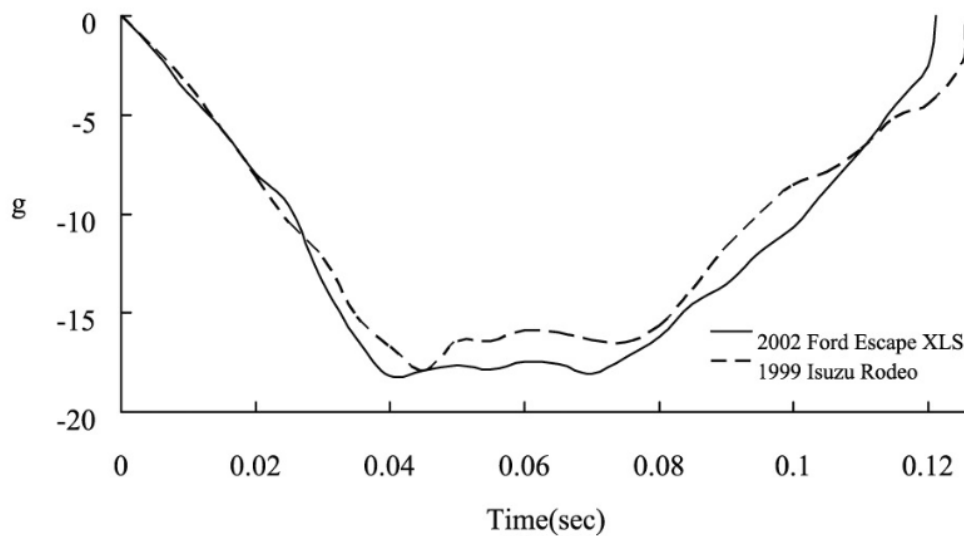


Figure 5.1 Comparison between Ford Escape XLS crash pulse curve and Isuzu Rodeo crash pulse curve.

The provided figure (Teng et al., 2017) illustrates a graph comparing the negative acceleration observed in the frontal crash pulses of a 2002 Ford Escape XLS and a 1999 Isuzu Rodeo. The crash pulses exhibit a relatively similar area and time duration for both vehicles. However, it is noteworthy that the 1999 Isuzu Rodeo demonstrates a higher maximum acceleration compared to the Ford Escape XLS. Additionally, according to Pawel Zal from the automobile catalog, the 2002 Ford Escape has a gross weight of 2054 kg, while the 1999 Isuzu Rodeo weighs 2200 kg.

6. Conclusion

The evolution of automotive structures stands as a testament to the relentless pursuit of safety, efficiency, and innovation in the automobile industry. From the early days of sturdy ladder frame designs to the contemporary era of lightweight yet robust unibody and monocoque structures, the journey has been marked by technological leaps. Manufacturing and material advancements have played a pivotal role, ushering in an era where high-strength steel alloys, aluminum, and composite materials fuse to create vehicles that are not just safer but also more fuel-efficient and environmentally conscious. Regulations and consumer-driven testing, as demonstrated by organizations like ANCAP & EuroNCAP. These not only give manufacturers a baseline but also give buyers confidence by demonstrating how crucial safety is when purchasing a car. This regulatory framework propels the industry towards continuous improvement and technological innovation, fostering a competitive market where safety is a defining factor. The comparison with frontal crash forces highlights the dynamic interplay between design considerations, material choices, and real-world performance. Understanding the nuances of structural behavior during impacts provides valuable insights for enhancing crashworthiness further. As we stand on the cusp of an electric vehicle revolution, the chassis landscape is undergoing yet another transformation. Specialized designs cater to the unique challenges posed by electric cars, with a focus on battery placement, weight distribution, advanced charging and overall performance. In summary, the automotive industry is at the cutting edge of modern technology and safety developments because it adheres to previous safety standards and innovative views concerning present challenges. The future offers not only environmentally friendly and efficient vehicles but also structures that push the limits of sustainability and safety. As we progress ahead, each development will help us get closer to a day when transportation is associated with efficiency, safety, and environmental responsibility.

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