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Electric Vehicle Structures

Automotive Chassis Systems | ACHA5013

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1 Introduction

Over time, the design of automotive chassis has undergone significant changes in response to shifts in powertrain systems, vehicle application, and even styling trends. These changes have shaped the way that vehicles are built and have had a profound impact on the performance and capabilities of modern automobiles.

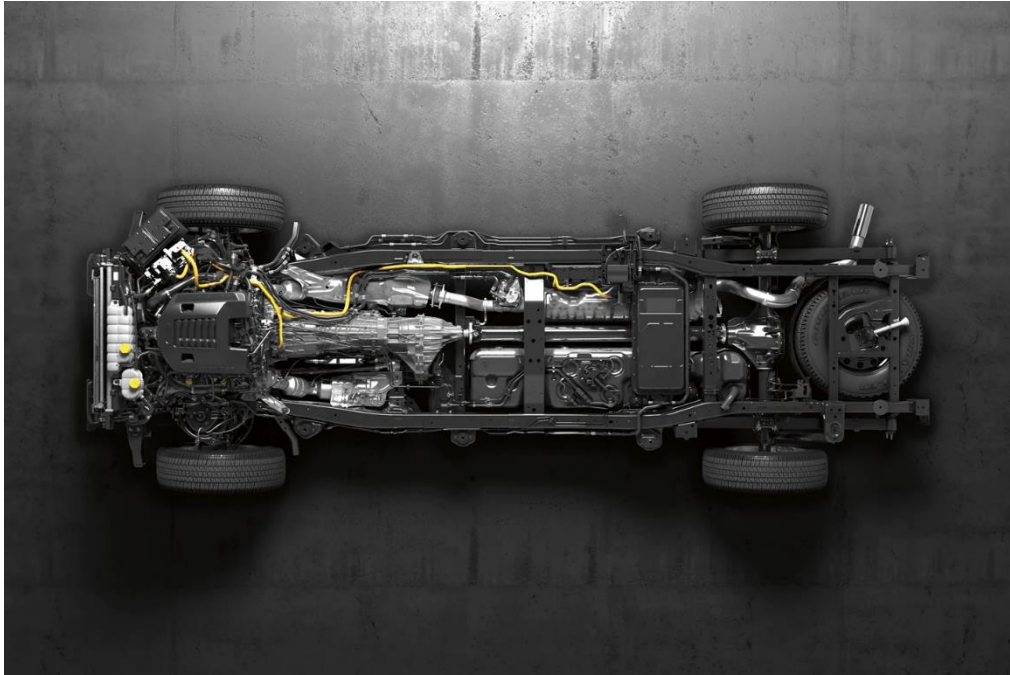


Figure 1 - Ford F150 Chassis (Ford Motor Co, n.d.)

This report will examine the history of chassis and body design in the automotive industry, from the early days of the automobile to the present day. By taking a retrospective approach, we can gain insight into the evolution of automotive construction and how it may adapt to the changing landscape of powertrain technologies, including the rise of electric vehicles and alternative fuels. This will help us to better understand the future of automotive construction and how it may respond to these emerging trends.

2 Automotive Structure History

2.1 Body on Frame

The history of automotive structures is closely tied to the evolution of the automobile as a whole. The need to create a horse-less carriage in the late 18th century sparked a revolution in transportation and led to the development of the first automobiles. During this time, many existing technologies from horse-drawn carriages were adapted for use in the construction of automobiles. This included the use of wooden frames and metal plates for the body, as well as the use of springs and wheels that were similar to those used on carriages. As the automobile industry grew and developed, new materials and technologies were introduced that allowed for the creation of more advanced and efficient body structures.



Figure 2 - 1905 Alldays & Onions (Bonhams, 2010)

The ladder chassis, also known as a body-on-frame chassis, is a type of vehicle body design that was developed during the early days of the automotive industry. This design is characterized by two longitudinal beams (usually made of steel) that are linked by transverse cross members. The ladder chassis was widely used in the production of automobiles and was primarily designed to resist bending forces. However, this type of chassis has poor torsional stiffness and is not well suited to handling high levels of twisting forces. Additionally, the ladder chassis design causes the body and chassis to behave as two separate springs when subjected to loads, which can lead to unpredictable behaviour and complicate the calculation of stiffness. (Brown et al., 2002, p.32)

The ladder chassis, while largely replaced by more advanced body designs, is still used in certain applications where its modularity, low cost, and robustness are important. For example, this type of chassis is often used in off-road and commercial vehicles, where it is subjected to harsh and demanding conditions. The ladder chassis is known for its ability to accommodate a wide range of

body structures with little or no modification, making it a versatile and cost-effective option for these types of applications. Despite its limitations, the ladder chassis continues to be a popular choice for certain types of vehicles due to its durability and simplicity.

As the automotive industry has evolved and vehicles have become capable of achieving higher speeds, the demands placed on the assembly have increased. To meet these demands, manufacturers felt the need to develop structure designs that are stronger and more rigid, with improved torsional stiffness. One example of this is the X-Frame design developed by General Motors in 1959. This design featured two cross members that formed an X-shape underneath the passenger area, allowing for a lower roofline while still providing ample legroom for passengers. (Milliken & Parker, 1958) Another example of a similar body design is the platform chassis, which was used in vehicles like the Renault 4 and the Volkswagen Beetle. This design features a chassis that is integrated into the floor of the vehicle, creating a single structural element that supports the body and the mechanical components.

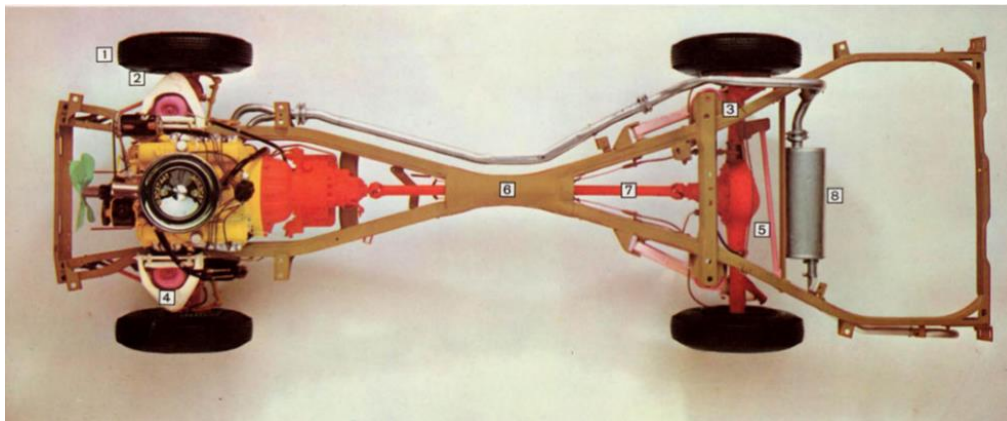


Figure 3 - General Motors' X-Frame (Milliken & Parker, 1958)

Renault R4 + R4 F4



Figure 4 - Renault 4 Platform Chassis (der Franzose Automobiltechnik GmbH, n.d.)

The backbone structure is a type of vehicle body design that is characterized by an increased cross-sectional area of the main structural members. This design is intended to increase torsional stiffness, which can improve the vehicle's handling and performance. The backbone structure is often used in specialist vehicles, such as the Lotus Elan/Esprit and the DeLorean DMC-12 and is typically made of stamped sheet metal or triangulated tube structures. The increased cross-sectional area of the backbone structure allows it to better resist torsional forces, which can be particularly beneficial in high-performance applications where the frame is subjected to higher loads. However, this type of structure can also be more complex and expensive to manufacture compared to other chassis designs.



Figure 5 - DeLorean DMC-12 Chassis (DeLorean Directory, n.d.)

2.2 Triangulated Structure

The triangulated structure is a type of vehicle chassis design in which the body panels are attached to a series of interconnected triangles. This design allows for increased cross-sectional area, which can improve torsional rigidity, especially if a roll cage is integrated into the design. The backbone structure is also known for its low tooling costs and reduced weight, but it has not been widely used in mass production due to the labour-intensive nature of the manufacturing process, which can reduce repeatability. This type of structure is often used in motorsport and high-performance vehicles, where the benefits of its strength and rigidity outweigh the additional manufacturing costs.



Figure 6 - Caterham 7 Triangulated Frame (Motortrend, 2016)

2.3 Space Frame Chassis

The space frame chassis, also known as a birdcage chassis, is a type of vehicle body structure in which the members are connected in a specific order and are either in tension or compression. (Dr. Mehdi Setareh, 2010) This design allows the structure to have high torsional rigidity while still being relatively lightweight. The space frame chassis is often made of aluminium or other lightweight materials and is commonly used in racing and high-performance vehicles. In 1994, Audi introduced this type of chassis to its road cars with the launch of the Audi A8, which featured a space frame chassis made of aluminium. This allowed the manufacturer to achieve a weight saving of 40% compared to a similar steel structure. (Audi Technology Portal, n.d.) The space frame chassis is known for its strength and rigidity, but it can also be more complex and expensive to manufacture compared to other types of chassis.

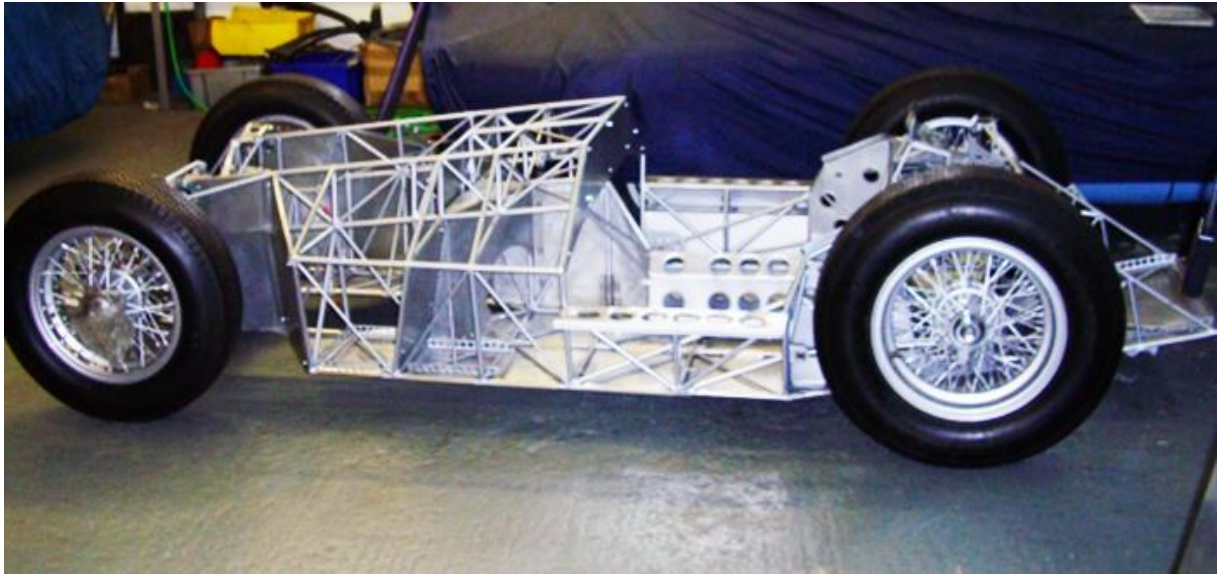


Figure 7 - Maserati Tipo 61 Birdcage Structure (Wikimedia Commons, 2013)

Der neue Audi A8

Audi Space Frame

The new Audi A8

Audi Space Frame

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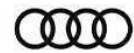


Figure 8 - Audi A8 Space Frame (Audi Technology Portal, n.d.)

2.4 Unibody

Another important development was the use of unibody construction. In this design, the body of the vehicle and the chassis are integrated into a single structure. (Undercoffler, 2017) This allows for a lighter and more rigid chassis, which can improve performance, handling, fuel efficiency and crash safety standards. However, unibody construction can also be more expensive to manufacture by the sheer amount of capital investment in equipment, this is usually mitigated by the way this design lends itself well to mass production with the steel pressings being easily spotwelded together by robotised manufacturing techniques.



Figure 9 - Unibody Chassis Body in White (Summit Racing Equipment, 2020)

2.5 Monocoque

Monocoque construction is a type of vehicle body design in which the body structure consists in both the chassis and the external skin of the vehicle. This construction method is often used in high-end sports cars or motorsport applications because it allows for significant weight reduction while still being able to withstand high loads. Monocoque vehicles are typically made of metal alloys or composite materials and are known for their "closed off" appearance, with higher sills that can make passenger ingress and egress more difficult. Monocoque construction is generally considered to be more rigid and lightweight than other body construction methods, but it can also be more expensive to manufacture.



Figure 10 - Carbon Fibre Monocoque (McLaren Automotive, 2019)

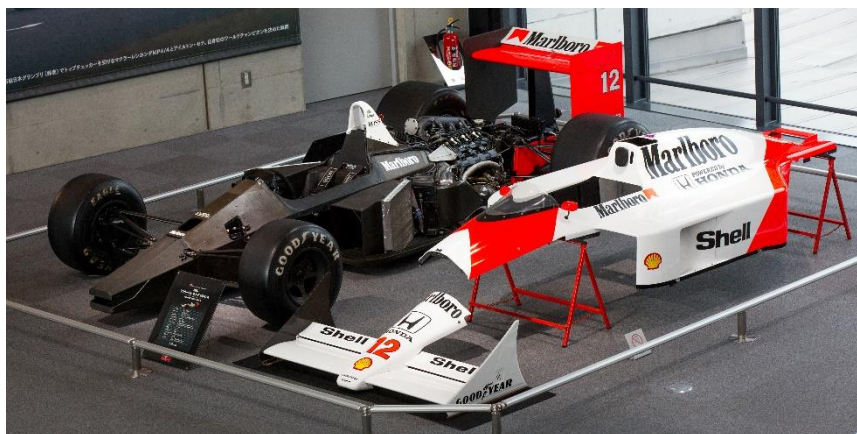


Figure 11 - McLaren MP4-4 Formula 1 Car (Wikimedia Commons, 2015)

3 The Future of Battery Electric Vehicle Structures

In the automotive industry, there has been a shift towards using more advanced materials, such as carbon fibre and high-strength steel, in the construction of vehicle chassis. These materials offer a strong and lightweight alternative to traditional materials, which can improve a vehicle's performance, handling, and fuel efficiency. Additionally, manufacturers have been using modular and flexible chassis designs that allow for the production of a wider range of vehicles on a single platform, reducing the cost of manufacturing. In an effort to reduce costs and make EVs more familiar to consumers, many manufacturers have chosen to build their electric variants using the same unibody construction as their internal combustion engine (ICE) vehicles. This approach can help to ease the transition to EVs for consumers, as the vehicle maintains a familiar appearance. For example, when Tesla introduced the Model S in 2012, the company used a contrasting panel in place of a traditional front grille in order to make the EV appear more similar to a traditional saloon car. While this approach can help to make EVs more accessible to a wider audience, it may not always be the most efficient or effective way to design an EV.



Figure 12 - 2012 Tesla Model S (Autoevolution, n.d.)

Electric vehicles typically have a simpler powertrain compared to ICE vehicles. ICE vehicles often have their large and complex powertrains located at the front of the vehicle. This can affect the weight distribution of the vehicle and make it more difficult to design deformable structures that can absorb impact during a crash. Additionally, the high-voltage battery in an EV may pose specific safety concerns in the event of a crash. However, the design of the motor and battery in an EV often allows for improved crashworthiness, as they are typically positioned away from the area of the vehicle that is designed to absorb impact during a crash. Their low centre of gravity also provides reduced chances of rollover events.

Electric vehicles offer some unique advantages in terms of aerodynamics compared to traditional internal combustion engine vehicles. For example, EVs tend to have a more streamlined body shape due to the lack of an ICE and related components such as an exhaust system. This allows for more flexibility in the design of the vehicle and can make it easier to incorporate features such as a flat floor or a redesigned passenger compartment, which can help to improve the aerodynamics of the vehicle.



Figure 13 - BMW i3 Platform (BMW Group, 2013)

In terms of chassis design for EVs, they offer the ability to either use the powertrain as a chassis like in the BMW i3, where it reminisces the platform chassis previously mentioned with a carbon-fibre-reinforced plastic passenger cell on top. This approach allows manufacturers to streamline production processes and reduce costs by leveraging economies of scale. This allows manufacturers to produce a range of vehicles, such as hatchbacks, saloons, SUVs, and commercial vehicles, using a shared set of core components. One company trying to introduce this is Canoo, who is focused on developing a modular and scalable platform for its vehicles. This platform serves as the foundation for a variety of electric vehicles, including vans, SUVs, and pickup trucks. (Canoo, n.d.)



Figure 14 - Canoo Electric Skateboard Platform (Canoo, n.d.)



Figure 15 - Canoo's Vehicle Line-up (Canoo, n.d.)

Many major automakers are now developing modular platforms for their electric vehicles, one example is Volkswagen's Modular Electrification Toolkit (MEB), which is a modular platform specifically designed for electric vehicles. All of Volkswagen's iD models, including the ID.3 hatchback and the ID.4 SUV, are based on the MEB platform. (Volkswagen Newsroom, n.d.)

Another example is Hyundai Motor Group's Electric Global Modular Platform (E-GMP), which is a modular platform that is being developed for use in a range of electric vehicles produced by Hyundai and its affiliates, including Kia and Genesis. The E-GMP platform is designed to support a wide range of vehicle sizes and powertrain configurations, and it is intended to be a key component of Hyundai's strategy for electrification. (Hyundai Worldwide, n.d.)

Another possible approach to EV chassis design is integrating the battery into the unibody structure, in since the battery is typically housed in a separate enclosure or pack. Integrating the battery into the unibody structure of an electric vehicle can help to improve the overall structural and torsional rigidity of the vehicle. A bit similar to the design of aircraft fuel tanks where the tank is incorporated into the structure of the wing, resulting in a lighter and more rigid overall design.

4 Van in Torsion

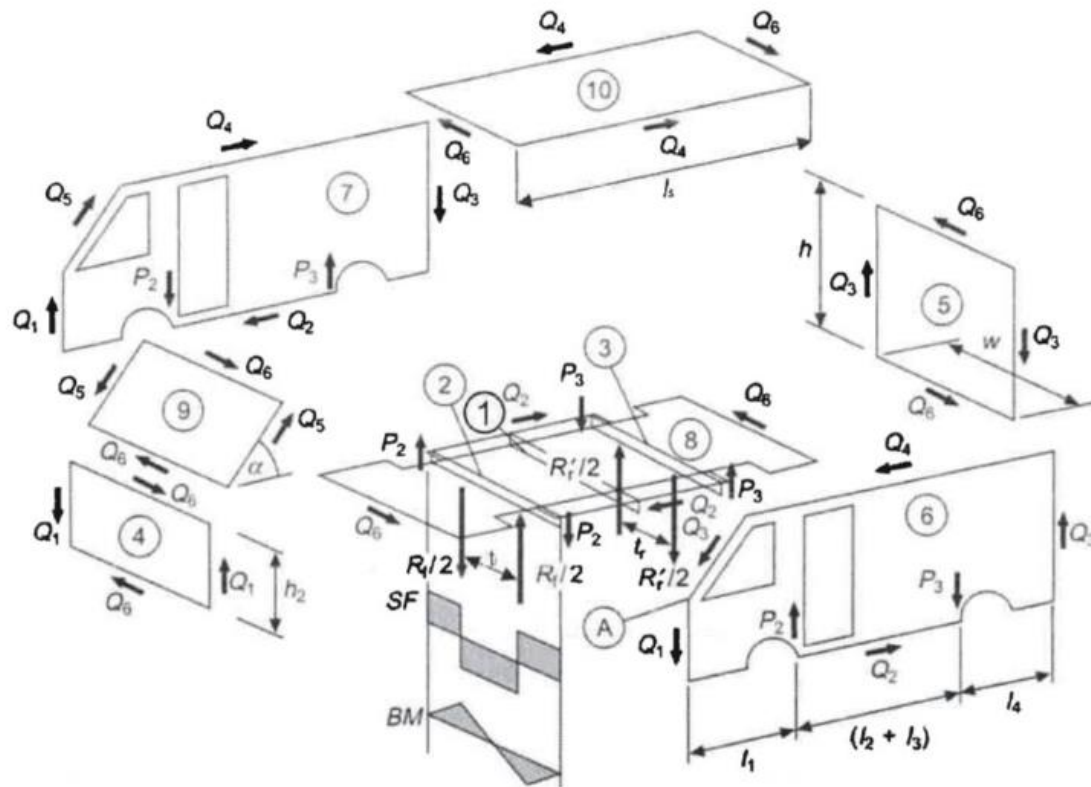


Figure 16 - Van in Torsion Example Provided

$$w=2.1\text{m}$$

$$h_1=2.5\text{m}$$

$$h_2=1\text{m}$$

$$l_1=2\text{m}$$

$$l_2+l_3=3.5\text{m}$$

$$l_4=1\text{m}$$

$$\text{Overall weight} = 3500\text{kg}$$

$$\text{Weight distribution} = 50:50$$

$$t_f = 1.5\text{m}$$

$$t_r = 1.5\text{m}$$

$$\alpha = 45^\circ$$

$$R_r = R_f = 5\text{kN}$$

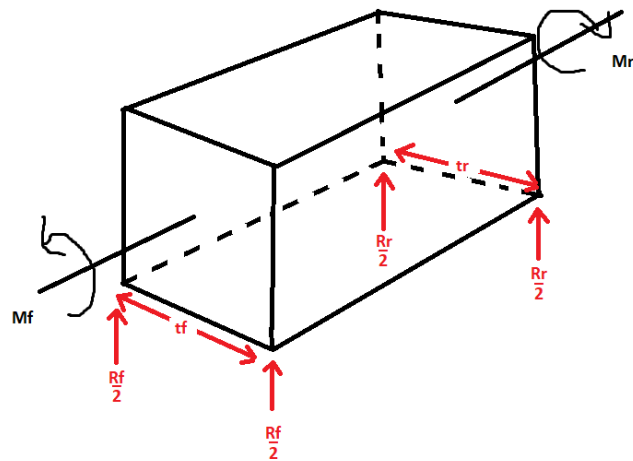


Figure 17 - Entire Van Force Diagram

Considering global vehicle:

$$M_f = M_r$$

$$\frac{R_f}{2} \times t_f = \frac{R_r}{2} \times t_r$$

SSS-2 (Front Cross Beam)

Taking moments from the centre

$$M \cup = \cup M$$

$$\frac{P_2 \times W}{2} + \frac{P_2 \times W}{2} = \frac{R_f}{2} \times \frac{tr}{2} + \frac{R_f}{2} \times \frac{tf}{2}$$

$$P_2 W = \frac{R_f \times t_f}{2}$$

$$P_2 W - \frac{R_f \times t_f}{2} = 0$$

$$P_2 W = \frac{5000 \times 1.5}{2}$$

$$P_2 = \frac{3750}{2.1}$$

$$P_2 = 1.79 \times 10^3 \text{ N}$$

SSS-3 (Rear Cross Beam)

$$P_3 W - \frac{Rr \times tr}{2} = 0$$

$$P_3 W = \frac{5000 \times 1.5}{2}$$

$$P_3 = 1.79 \times 10^3 N$$

SSS-4 (Front Panel)

$$M \curvearrowright = \curvearrowright M$$

$$Q_6 \times h_2 = Q_1 \times W$$

$$1: Q_1 = \frac{Q_6 \times h_2}{w}$$

SSS-5 (Rear Door Frame)

$$M \curvearrowright = \curvearrowright M$$

$$Q_3 \times W = Q_6 \times h_1$$

$$2: Q_3 = \frac{Q_6 \times h_1}{W}$$

SSS-6 (Body Side Panel)

Taking moments @ A

$$M \curvearrowright = \curvearrowright M$$

$$P_3(l_1 + l_2 + l_3) = Q_4(h_1 - h_2) + Q_3(l_1 + l_2 + l_3) + Q_2 \times h_2 + P_2 \times h_1$$

$$3: P_3(l_1 + l_2 + l_3) - Q_4(h_1 - h_2) - Q_3(l_1 + l_2 + l_3) - Q_2 \times h_2 + P_2 \times h_1 = 0$$

SSS-7 (Body Side Panel #2)

Same as previous.

SSS-8 (Floor Panel)

$$M \cup = \cup M$$

$$Q_2 \times W = Q_6 (l_1 + l_2 + l_3 + l_4)$$

$$4: Q_2 = \frac{Q_6 (l_1 + l_2 + l_3 + l_4)}{W}$$

SSS-9 (Windscreen Panel)

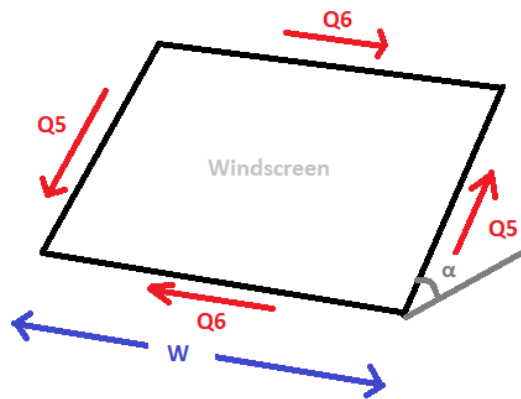


Figure 18 - Windscreen Stress Diagram

$$\sin \alpha = \frac{h_1 - h_2}{H}$$

$$H = \frac{h_1 - h_2}{\sin \alpha}$$

$$M \cup = \cup M$$

$$\frac{Q_6 (h_1 - h_2)}{\sin \alpha} = Q_5 \times W$$

$$5: Q_5 = \frac{Q_6 (h_1 - h_2)}{W \times \sin \alpha}$$

SSS-10 (Roof Panel)

$$M \cup = \cup M$$

$$Q_6 \times l_5 = Q_4 \times W$$

$$6) Q_4 = \frac{Q_6 \times l_5}{W}$$

Using equation number 3 and substituting in Q1 through Q5 and rearranging for Q6:

$$P_3(l_1 + l_2 + l_3) - Q_3(l_1 + l_2 + l_3 + l_4) - Q_4(h_1 - h_2) - Q_2 \times h_2 - P_2 \times h_1 = 0$$

$$P_3(l_1 + l_2 + l_3) - \frac{Q_6 \times h_1}{W}(l_1 + l_2 + l_3 + l_4) - \frac{Q_6 \times l_5}{W}(h_1 - h_2) - \frac{Q_6(l_1 + l_2 + l_3 + l_4)}{W} \times h_2 - P_2 \times h_1 = 0$$

$$P_3(l_1 + l_2 + l_3) - P_2 \times h_1 = \frac{Q_6 \times h_1}{W}(l_1 + l_2 + l_3 + l_4) + \frac{Q_6 \times l_5}{W}(h_1 - h_2) + \frac{Q_6(l_1 + l_2 + l_3 + l_4)}{W} \times h_2$$

$$P_3(l_1 + l_2 + l_3) - P_2 \times h_1 = \frac{Q_6}{W}[h_1(l_1 + l_2 + l_3 + l_4) + l_5(h_1 - h_2) + h_2(l_1 + l_2 + l_3 + l_4)]$$

$$\frac{W[P_3(l_1 + l_2 + l_3) - P_2 \times h_1]}{[h_1(l_1 + l_2 + l_3 + l_4) + l_5(h_1 - h_2) + h_2(l_1 + l_2 + l_3 + l_4)]} = Q_6$$

Solving for Q6:

$$Q_6 = \frac{2.1 [1.79 \times 10^3(2 + 3.5) - 1.79 \times 10^3 \times 2.5]}{[2.5(2 + 3.5 + 1) + 5(2.5 - 1) + 1(2 + 3.5 + 1)]}$$

$$Q_6 = 372.79N$$

Using Q6 to solve Q1:

$$Q_1 = \frac{Q_6 \times h_2}{W}$$

$$Q_1 = \frac{372.79 \times 1}{2.1}$$

$$Q_1 = 177.52N$$

Using Q_6 to solve Q_2 :

$$Q_2 = \frac{Q_6 (l_1 + l_2 + l_3 + l_4)}{W}$$

$$Q_2 = \frac{372.79 (2 + 3.5 + 1)}{2.1}$$

$$\mathbf{Q_2 = 1153.87N}$$

Using Q_6 to solve Q_3 :

$$Q_3 = \frac{Q_6 \times h_1}{W}$$

$$Q_3 = \frac{372.79 \times 2.5}{2.1}$$

$$\mathbf{Q_3 = 443.80N}$$

Using Q_6 to solve Q_4 :

$$Q_4 = \frac{Q_6 \times l_5}{W}$$

$$Q_4 = \frac{372.79 \times 5}{2.1}$$

$$\mathbf{Q_4 = 887.60N}$$

Using Q_6 to solve Q_5 :

$$Q_5 = \frac{Q_6 (h_1 - h_2)}{W \times \sin \alpha}$$

$$Q_5 = \frac{372.79 (2.5 - 1)}{2.1 \times \sin 45^\circ}$$

$$\mathbf{Q_5 = 376.57N}$$

Panel no. 4 Total Loads

$$Total\ loads_{panel\ #4} = 2 \times Q_6 + 2 \times Q_1$$

$$Total\ loads_{panel\ #4} = 1100.62\ N$$

Panel no. 5 Total Loads

$$Total\ loads_{panel\ #5} = 2 \times Q_6 + 2 \times Q_3$$

$$Total\ loads_{panel\ #5} = 1633.18\ N$$

Panel no. 6 Total Loads

$$Total\ loads_{panel\ #6} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$

$$Total\ loads_{panel\ #6} = 3039.36\ N$$

Panel no. 7 Total Loads

$$Total\ loads_{panel\ #7} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$

$$Total\ loads_{panel\ #7} = 3039.36\ N$$

Panel no. 8 Total Loads

$$Total\ loads_{panel\ #8} = 2 \times Q_6 + 2 \times Q_2$$

$$Total\ loads_{panel\ #8} = 3053.32\ N$$

The panel with the least amount of weight or force applied to it is the front panel (number 4), followed by the rear panel (number 5). The side panels of the van (numbers 6 and 7) are next, with the panel that bears the most weight or force being the floor panel (number 8).

If the joint between the rear panel and floor panel is removed in order to provide battery interchangeability, the structure will lose an important point of support and will be unable to distribute the weight and forces it is subjected to as effectively. As a result, these loads and forces will have to be absorbed by other joints in the structure, which may not be able to handle the additional strain. This can potentially lead to the structure being overloaded and collapsing. It is important to carefully consider the consequences of removing any joint in a structure, as it can negatively impact the overall stability and load-bearing capacity of the structure. However, it may be possible to mitigate these effects by reinforcing other joints in the structure to compensate for the loss of the rear panel and floor panel joint.

5 Conclusion

The history of automotive chassis design has been shaped by various factors such as improvements in materials and manufacturing methods, as well as changes in safety regulations. Early chassis designs were simple and sturdy, with little focus on reducing weight or enhancing handling. As cars became more advanced and performance-based, chassis design became more complex and focused on factors like stiffness, torsional rigidity and weight distribution.

The rise of electric vehicles has also had a major impact on the future of automotive chassis design. These vehicles tend to have a lower centre of gravity compared to gasoline-powered cars, which leads to better handling and stability. Additionally, the absence of a traditional internal combustion engine allows for more flexibility in chassis layout, as there is no need to incorporate a large engine and transmission.

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