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Automotive Chassis Systems

Sill and tunnel sizing for frontal crash

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Introduction

This report will look at the development of vehicle structures over history. This includes factors which have caused the development such as torsion, bending, aerodynamics and crash requirements. On top of this manufacturing and materials which have influenced the development of vehicle structures will be covered, taking into consideration consumer driven testing such as EuroNCAP. This report will also look at the frontal crash characteristics of an Audi R8 Spyder. Calculating what the size requirements are for these parts for effective occupant protection.

Chapter 1: Development of vehicle structures over history

Vehicle structures have come a very far way since the first variations in the form of horse drawn carriages. Starting off as simple wooden frames with metal reinforcements, the first vehicle structures lacked rigidity and were highly flexible under load. In fact, they were intentionally made flexible with fabric skins to act as a form of suspension. Because the body and the chassis were separate, they would behave like parallel springs, resulting in the load transfer to be proportional to relative stiffness.



Figure 1: Typical horse drawn carriage

Wood has been used for carriages for hundreds of years, constructed by hand by skilled craftpersons who often have developed their skills from generations of family members in the same trade (G.Wand, 2017). During this period, there was no standardization in designs. Each vehicle was custom-built, which made mass production nearly impossible (Build Matt Ltd, 2025). Factors such as aerodynamics and crash safety were not even considered, which was not as much of an issue at the time as the vehicles were not capable of high speeds. When Henry Ford introduced his model T in 1908, it sold on its low price and utility rather than its looks, however over its 19 years of production the body design changed, a reflection of customer taste also changing (A.Livesey, 2018).

The introduction of steel frames improved the structural rigidity and flexibility under load issues for the first self-powered cars. However, it leads to new issues such as being too heavy, a result of the body and chassis being separate and wood still being utilised similar to how carriages were constructed.

The reason car companies use steel according to World Auto Steel is because, “steel is the easiest and best material for designing safe vehicles.” It has a unique ability to absorb an impact and diffuse crash energy. In fact, it can become harder when it’s crushed, meaning it becomes stronger on impact and can absorb more energy (N.Spira, 2025).

The monocoque or more commonly known as the unibody significantly improved the torsional and bending stiffness of the vehicle by integrating the body and the chassis into a singular structure. The 1930s saw greater emphasis on streamlining design. Manufacturers began to use wind tunnels to eliminate unnecessary drag-inducing projections from their cars. One of the dominant styling features of the 1950s and 1960s was the tail fin, inspired by the twin tail fins of the wartime Lockheed Lightning fighter aircraft (A.Livesey, 2018). During the 1930s-50s fuel was so cheap fuel and plentiful fuel consumption was not an important factor like it is today (G.Wand, 2017).

Around this time was also when the first crash safety measures would begin to be incorporated in structural designs. Including new concepts like crumple zones and 3-point seatbelts, which significantly changed how chassis were being made. First installed by Mercedes in 1959 on their Mercedes-Benz 220 (SMMT, 2015) crumple zones involve intentionally making areas on the chassis to collapse in a controlled manner to take as much force out of the impact before it reaches the occupant’s cabin. Crash safety features like this became import crash requirements as vehicles became faster.



Figure 2: 1959 Mercedes-Benz 220

Fuel consumption was now a factor vehicle designers had to consider especially during the oil crisis in the 1970s. This led to more focus developing the aerodynamics of a vehicle, which has a direct effect on fuel efficiency, leaving behind the excessive features for more streamlined designs. As vehicles developed they became larger, this increase in breadth and depth also meant an increase in bending. Suspension was also massively improving, so the need for a stiffer chassis was clear. Perimeter space frames delivered this with a considerable increase in torsional rigidity. They achieved higher levels of stiffness with small sections of tubular structures built into stiff jointed bays.

Unitary body structures took this even further. A mixture between monocoque and perimeter space frames it is the most widely used modern car structure. While still providing the required stiffness, unitary body structures can be spot welded, making them well suited for mass production. Traditionally made out of stamped sheet steel, however now materials like aluminium and carbon fibre are being used to make the chassis even lighter and stiffer. Typical values for torsional stiffness in a modern passenger car are in the range of 17000 to 40000 Nm/deg, with a roll stiffness of 1000-2500 Nm/deg per axle (O.DANIELSSON, 2024). Typical wooden carriages have a torsional stiffness of 500 – 2000 Nm/deg, so this really shows how far chassis design has come over the years.

In the modern era the rise of electric vehicles has led to the integration of electric powertrains within chassis design. Battery packs are often integrated into the floor of the vehicle, enabling a lower centre of gravity, better weight distribution, and improved handling characteristics (TAAL, 2023). Companies now also have started taking advantage of modular chassis platforms which enable the sharing of components, including chassis structures, between different vehicle types, such as sedans, SUVs, and crossovers, maximizing economies of scale and reducing production costs (TAAL, 2023).

Impacts on chassis design

A way safety has affected chassis design is pedestrian collisions. Car companies now have to consider how a pedestrian will be affected when being ran over by their new vehicle. This includes how tall the front of the vehicle is, where the head of the pedestrian will land, how will the legs react and more. These all now have an influence on how the front of the chassis is designed. Vehicle chassis design can also massively vary based on region. In America they design chassis to have very good roll over ratings as that is the most common crash type in the USA. They also have to incorporate larger airbags to make up for the larger average weight of customers compared to Europe. Meanwhile in Europe the most common crash types are rear ends, therefore chassis designed for the European market have very well-designed crumple zones.

The European New Car Assessment Programme (Euro NCAP) is a European voluntary car safety test that was introduced in 1996. Euro NCAP publish safety reports on new cars, and awards 'star ratings' based on the performance of the vehicles in a variety of crash tests (EuroNCAP, 2025). This includes front, side, pole impacts, and impacts with pedestrians which are all recorded and posted online for everyone to see. Testing is not mandatory, with vehicle models either being independently chosen by Euro NCAP or sponsored by the manufacturers. Despite the fact that the euro NCAP is not mandatory, it holds such a high level of trust with consumers that a vehicles NCAP rating will heavily influence a customer purchasing a new vehicle. And if a vehicle does not have a NCAP rating, they will often avoid that vehicle completely.

Therefore, the introduction of the euro NCAP had a massive impact on the design of vehicle chassis. Car companies now had to make sure their new vehicles would be able to pass the thorough NCAP test or no one would buy it. This meant increasing the focus on crash safety beyond the government set regulations and specifically designing chassis to be able to withstand the tests. As a result, vehicles chassis became stronger, had better designed crumple zones, airbags in the doors and more.

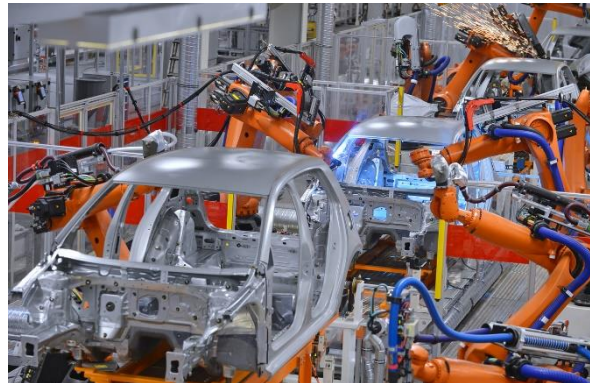


Figure 3: Modern Car factory

Something that also had a massive impact on vehicle design was the introduction of an industrial robot system into the manufacturing of vehicle chassis. First done by general motors in 1961, its main purpose was spot welding, but over time its capabilities and therefore its responsibilities grew (Junair, 2021). This had a direct influence on how vehicle chassis were designed as car manufacturers would now design vehicle chassis in a way that the robot could mass produce it. This massively decreased production time and in turn costs, while also increasing profits all at the same time.

Development of materials has also had an influence on vehicle chassis design. An example of this is Lightweighting and the different materials that can be used in automobiles to make it effective. Manufacturers are pursuing strategies to reduce vehicle weight and improve fuel efficiency by using plastic and polymer composites rather than heavy metals. These materials minimise stress on parts, which can lead to better durability and fewer replacements (SINO, 2025).

The Road Vehicles (Authorised Weight) Regulations 1998 has a direct influence on vehicle chassis design as it specifies weight restrictions for vehicles. This means that car companies have to ensure that the vehicle can safely carry loads without compromising structural integrity (GOV.UK, 2023).

Chapter 2: Audi R8 Spyder Occupant protection

To use newtons second law to estimate the forces which must be resisted by the sills/tunnel, I need to have the mass of the Audi R8. The kerb weight of a 2020 Audi R8 Spyder is 1795kg (Car Specs, 2020). Now that I have the mass, I need the acceleration to calculate the force. Using the typical frontal crash pulse given on the handout, it states that the most acceleration you will typically see is around 36g, or 353 meter per second squared.

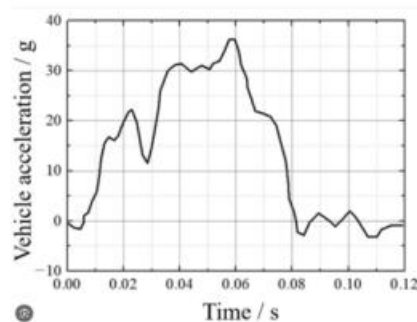


Figure 2: A typical frontal crash pulse

Figure 4: Typical frontal crash pulse

Therefore, using these figures we can calculate that the force is around 633,635 Newtons (353×1795). During a frontal crash, the sills and tunnel contribute to load bearing and energy absorption. So, we need to make some assumptions to figure out how much they need to contribute. If the crumple zone absorbs say 60% of the energy, then the remaining 40% of the force is transmitted to the sills, tunnel, and cabin structure. 40% of 633,635N is 253,454N.

This force has to be distributed between two side sills (left and right) and the transmission tunnel and the cabin structure. Assuming the side sill absorb 60% of the force on the cabin, each sill therefore will bear 76,036N of force ($(253,454 \times 0.6) / 2$). Then assuming the transmission tunnel absorbs 40% of the force on the cabin, the tunnel will experience 101,382N ($0.4 \times 253,454$).

The stress on the materials should stay below yield strength to avoid cabin collapse. Ultra-High Strength steels (UHSS) are a type of specially formulated steel with a tensile strength above 780 Mpa (N.Spira, 2025). For sills and tunnels in the automotive industry, press-hardened steel (PHS) is typically used which has a yield strength of 1050Mpa (E.Billur, 2025). Therefore, using the stress equation, $\text{Stress} = \text{Force} / \text{Area}$, we can calculate the minimum cross-sectional area of each component. Giving a minimum cross-sectional area of 72.4mm^2 for each side sill and 96.6mm^2 for the transmission tunnel.

So, to meet these requirements, the side sills would need a cross section of 80mm by 80mm with a wall thickness of 1.5mm. This gives the side sills a cross-sectional

area of around 94mm^2 exceeding the 72.4mm^2 . And for the transmission tunnel a cross section with a diameter of 100mm and a wall thickness of 1.5mm will give the tunnel a cross-sectional area of around 141mm^2 , once again exceeding the required 96.6mm^2 . Utilizing Press-Hardened Steel the proposed dimensions for the side sills and transmission tunnel provide sufficient structural integrity to protect the vehicle's cabin and occupants during a 36g frontal crash.



Figure 5: 2020 Audi R8 Spyder

However, Audi uses multimaterials in the R8 to reduce weight and increase stiffness. The transmission tunnel is made out of carbon fibre and the side sills are made out of extruded aluminium (D.Prosser, 2015). Carbon fibre strength can range from 2.5 Gpa to 7 Gpa (Epsilon, 2025), so using a figure of 3 Gpa this gives the tunnel a new minimum cross-sectional area of 33.8mm^2 . A transmission tunnel with a diameter of 100mm and a wall thickness of 1.1mm would have a cross-sectional area of 34.5mm^2 , meeting the requirement. High quality extruded aluminium can have a strength of 480 Mpa (Gabrian, 2024). So, with this material the minimum cross-sectional area is now 158.4mm^2 . Therefore, to achieve this it needs a rectangular cross-section of 80mm x 80mm and a wall thickness of 2.1mm, giving it a cross-sectional area of 164mm^2 .

I am unable to compare these estimated section sizes to the actual sizes on the car because the cross-sectional area of the side sills and transmission for the 2020 Audi R8 Spyder or in fact any car is not publicly specified in the available technical documentation or official specifications. The side sills and tunnel contribute to the vehicle's structural integrity and aesthetics, but their exact measurements are not typically displayed online. A vehicle very similar to the R8 is the Lamborghini Gallardo which the R8 is actually based on, however the side sill and tunnel dimensions are also not displayed online. And considering my dimensions are estimated based off assumptions on energy dispersion, comparing this to a car that is not similar to the R8 would make a very weak comparison which would not tell me much on the accuracy of my estimation.

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