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Frontal Crash

Automotive Chassis Systems

ACHA5013

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1 Introduction

In this essay I will discuss how the automotive chassis have changed over time and explain the reasons for these changes. I will be talking about the cause of chassis innovations ranging from safety to speed including regulation changes, manufacturing and material developments and third-party testing taken out by companies such as Euro NCAP. I will also consider how these changes affect some of the success criteria of a car's chassis specifically its crash worthiness, torsional stiffness, resistance to bending and its effect on the aerodynamics of the final product.

This essay will also include a section where I calculate the buckling load (theoretical) for a body in white and compare and contrast my findings with the maximum forces found in a typical frontal crash pulse for the same or similar vehicle.

2 History of the automotive chassis

Automotive design has come a long way with innovations in speed and safety coming from material, manufacturing, and chassis design developments. This journey starts in 1770 when the first carriage was made. I am calling this the start of the journey because before the car, people used the horse and carriage to get around and it was effective but not fast. When we began to produce cars, we looked at these carriages as a starting point. In the Late 19th century, the early cars were essentially carriages adapted from the horse pulled system to work with internal combustion engines.

An automotive chassis can be defined as the load bearing structural frame on which other components are mounted to. (Anon., n.d.)

2.1 Pre 1900

When we started to manufacture cars in the Late 19th Century, nobody knew much about what makes a good chassis. Their success criteria were very different from what we see today. They saw the frame as the structure of the car and the body as no more than seating and storage, this 2-part chassis is referred to as a body on frame design.

The body was assumed to be non-load bearing and the frame was designed to deal with all the forces acting on the car. When looking at chassis performance this design is not a good design, these cars were made almost entirely from wood and did not cope well with the forces running acting on them, it was especially poor at dealing with torsional forces because the frame and body does not work together to distribute the energy.

2.2 1900-1910

Cars up to 1901 were built primarily from wood. This led to many problems including a lack of stiffness.

By using other materials than wood in the body of the car, they hoped to improve issues such as poor durability, high manufacturing time, poor weather resistance, and of course its resistance to force (both torsional and bending forces).

In 1901 the Eastman steamer was the first car to introduce steel panels to its body and the following year the 1904 Marmon was the first to do this with aluminium. After the introduction of metal body work other manufacturers followed suit. Steel was the more popular option with aluminium being found in only high-end cars due to it being more expensive to manufacture.

The introduction of steel sheet body's made cars

- More durable
- It streamlined the manufacturing (because handmade wooden body's took a long time to produce)
- Improved crash worthiness
- Increased the cars structural rigidity.

One of the original goals of adding metal sheet to the body of cars was to make the vehicle stiffer. Whilst it succeeded in making the body stiffer than it was before it also made the body stronger than the frame it was sitting on. This is a problem because when the body is stiffer than the frame, the load path will go through the body of the car which was not designed to cope with these forces. This issue created problems such as Frame flex which has a negative effect on the cars handling. Having a strong body on a relatively weak frame can create rattling and vibrations that can be heard by passengers. This is often referred to as NVH or noise vibration and harshness, it is an inconvenience for the drivers and passengers and is something that we try to avoid.

Car manufacturers connected the dots and realised that when the body is stiffer than the frame it creates these issues. There were 2 trains of thought on how to fix the issue. The first was to make the body weaker and the second was to make the frame stronger. Manufacturers experimented with both options, some made the body of their cars more flexible by adding more fabric and others looked to make the frame stiffer.

2.3 1910 – 1920

This era saw the introduction of armoured wood being used in vehicle frames.

Armoured wood played a significant role in the early history of car chassis because it marked the start of manufacturers trying to stiffen the cars frame. It was first seen on the Hupp mobile in 1911. Armoured wood refers to a wooden frame being reinforced

with steel or treated in its manufacturing process to make it more resistant to bending. Manufacturers identified weaker parts of the frame through repeated failures of the chassis and reinforced those parts of the frame using armoured wood. The engine mounting points was commonly the weakest part.

Now that the pursuit of stiffer frames had become it wasn't long before steel frames began to replace wooden frames.

The first steel frames were in the form of a simple ladder frame they had two side members running for the length of the car and cross members and reinforcements in the weaker areas of the frame as shown in figure 1

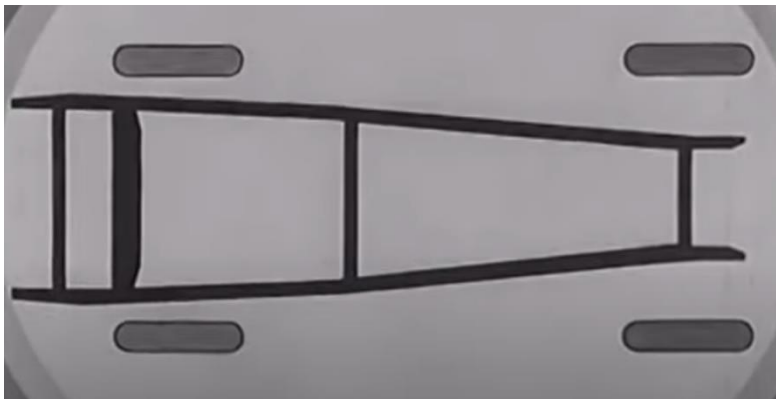


Figure 1 – Early steel frames

As people began to understand load paths better, these ladder frames became more complex and effective. They began to reinforce the central cross member to prevent lateral bending using techniques such as Crucible bracing. At this stage they were solely concerned with bending forces and had no consideration for torsional strength.

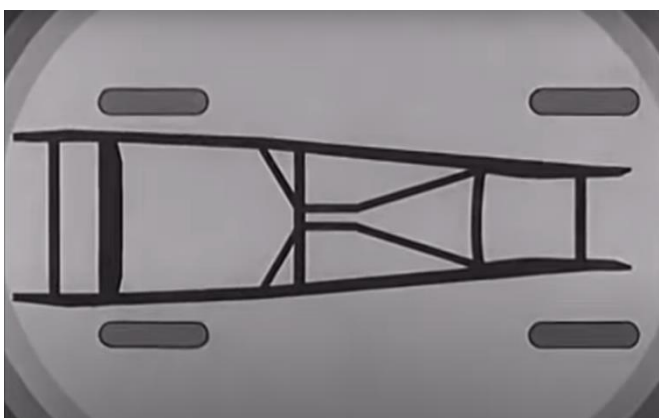


Figure 2- Advancement of the Ladder frame

These improvements were made with the aim of improved bending resistance. They came around because of developments in manufacturing processes allowing us to create steel

frames. This change in material gave cars of the time significantly better resistance to bending and torsion stiffness.

2.4 1920-1930

Early ladder frames were created with a unclosed cross section which looked like a c or a u depending on its orientation. Moving away from members with a “C” or “U” cross section to fully closed section members created much stiffer chassis. This increased both the bending and torsional resistance.

Arguably the most important discovery in chassis development was the realisation of the importance of torsional stiffness.

Hillman released a study they did showing a comparison between their own unibody and BoF (body on frame) designs as shown in figure 3

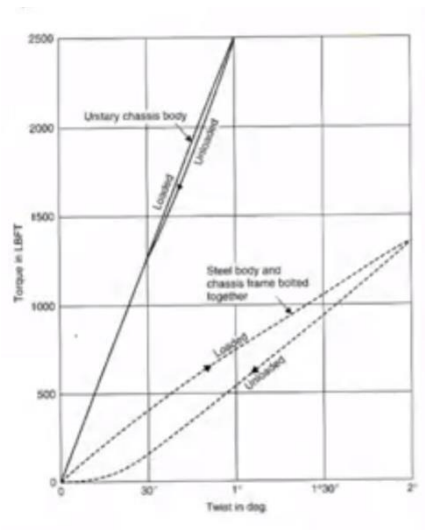


Figure 3- Hilman 10HP BoF vs unibody

Hilman realised that the body on frame design) acted like two springs running in parallel to each other and when you combine the two components into what we call a unibody chassis you will see massive gains in torsional stiffness.

Unibody refers to a chassis where the frame, body, any major chassis structural support and crash-protection components are joined into one by welding, bonding, moulding, or another method. As shown in Figure 3, when compared to the body on frame design, the unibody approach offers the potential for significant weight reductions and stiffness improvements but is more technically demanding to develop and manufacture. Figure 3 shows just how significant the switch to a unibody design was.

Lancia were the first manufacture to make a car with a unibody construction with the Lancia Lambda (1922-1931)

In this period, engineers began to understand that *Torsional stiffness* $\propto$ $(Area\ enclosed)^2$. This led to chassis having increased breadth and depth to create a larger enclosed area and create a chassis with better torsional stiffness. This led to the emergence of many different designs over the coming decades.

2.5 Triangulated tubes

This design is a series of tubing creating the frame of the car that manufacturers attach panels to. The body work does not need to be structural so it can be made as light as possible. Cars with this frame design will often have fiberglass body panels.

With this design there is no cut out for doors, in some cases the body will have a shallow cut out to where a door would typically be to make it easier to get in and out of the vehicle. Even with this compromise the cars were still difficult to enter and exit.

Years of development saw the tubular structure develop into the birdcage design. The main difference between the triangulated tubular structure and the birdcage design is the introduction of the roof of the car.

The chassis is cost effective because the tubes can be connected to one another easily, quickly, and cheaply by welding. This is the main reason it is so popular for lightweight race cars. The first car to have this chassis was the Maserati Tipo 61 which was released in 1959.

2.6 The Pure monocoque structure

The pure monocoque design consists of tubes with sheer panels attached. It is very light weight and very strong. In this design the engine and gearbox are stressed members to increase the rigidity of the vehicle. The pure monocoque is restricted to race cars because it requires a fully closed tube shell required reinforcement. This makes it extremely difficult to get in and out of the car.

2.7 The backbone structure

The backbone structure is a thick, fully closed cross section tube connected to both, the front and the rear axle of the car. This backbone carefully tucks the driveshaft away to protect it from harm. The drivetrain and engine are attached to the ends of this tube. This design allows for a better connection of the axles which enhances the stability of the car. The main drawback to the backbone design is that vital components such as the drive train are difficult to access so it makes repairs difficult and expensive.

The backbone structure was first seen in the tara 11. It is primarily seen is specialist sports car used as part of a body on frame chassis with light fiberglass body in cars made by companies such as lotus and tvr.

2.8 Punt/platform

A platform chassis is a body on frame design where there is a large single flat steel sheet, usually running for the full width of the car, but shorter in length only spanning the width between the wheels. The body is typically bolted to the platform at the end of construction. The weight of the engine, gearbox and suspension were typically supported by subframes.



Figure 4 - platform frame example

Space frame

2.9 Advancement in materials

Materials selecting for a vehicle chassis is very important. The material selection criteria will vary from car to car because of its application some want to be cheap to make some focus on strength and some focus on weight.

Material	Pros	Cons
Steel	• Strong • Durable • Cost affective	• Heavy • Corrosion
Aluminium	• Good strength to weight ratio • Corrosion resistance	• Cost
Carbon fibre	• Great strength to weight ratio • Allows for intricate design	• Cost • Manufacturing complexity
Fibre glass	• Light • Corrosion resistant	• Strength
Composites such as plastics	• Light • Corrosion resistant	• Strength • cost

2.10 Crash safety

Early chassis improvements did not have crash safety as their primary goal. Whilst many of them did make the vehicles safer it was rarely their main goal.

Safety improvements were made before the NCAP but the introduction of independent organisations such as NCAP gave manufacturers a reason to strive for safety because it created a direct link between safety and sales.

The Euro NCAP (European New Car Assessment Programme) is an independent organization that evaluates the safety of new vehicles sold in Europe. The vehicle being tested will get assessed across 4 metrics – adult occupant, child occupant, vulnerable road users and safety assists and will get a final score between 0 and 5 stars. This score will have a significant impact on the vehicles sales because the people care about safety more than they ever have.

Safety features such as seatbelts and airbags and crumple zones were invented with the primary goal of making vehicles safer and were before the NCAP.

These three inventions use the equation $F = ma$ to reduce the force applied on the people in the car. Mass is a constant for the driver because they do not get any lighter or heavier in the event of a crash. Therefore by reducing the acceleration of the body, you reduce the force applied to the body which will reduce the severity of the injuries sustained.

Euro NCAP influenced change when they introduced vulnerable road users. All of the cars on the road began to look a little different. To get a good score in this section of the test the front of your vehicle needed to be smooth and tall not low to the floor and angular like many cars were. Other than softer rounder front ends, most of the safety features added to vehicles influenced by organisations such as Euro NCAP have been electronic assists such as Pedestrian detection, lane departure warnings, autonomous emergency braking systems and many more.

3 Task 2

For this section of the report, I have selected the 2nd generation Ford Focus to be my body in white. This vehicle was produced between 2005 and 2010. This car was given 5 stars by Euro NCAP.

In the event of a frontal crash many elements of the chassis are affected namely the frame rails, crossmembers and sill panels. We were shown the importance of the sill panel in a video presented in a lecture (NCAP, 2023). The video showed a Rover 100 going through crash testing. During the offset barrier test the sill panel of the Rover 100 buckled allowing the front wheel to move which caused the car's dashboard and steering wheel to move. Because the steering wheel had moved, the airbag was deployed in the wrong place and was not effective. I have chosen to use the sill for this part of the assessment because of how important it is for the driver's safety in the event of a crash.



Figure 5 – sill panel from 2008 Ford Focus

The sill panel is made from steel and has a width of 150 mm and a length of 1800 mm and a height of 250 mm (Anon., 2024). Steel has a Young's modulus of 200 000 MPa (Anon., 2016) and a Poisson's Ratio of 0.265 (Anon., n.d.)

Euler's critical buckling equation (Lake, 2023) - $P_{cr} = \frac{\pi^2 \times E \times I}{(K \times L)^2}$

Before I can use this equation I need to find values for K and I. K represents effective length factor. Because the sill is fixed at both ends I can use the equation $k = L/2$ in this example K would be equal to 0.5 because K is a constant to multiply L by. (Engineering, 2021) In this equation, I represents the moment of inertia. I will use the equation $I = \frac{b \times h^3}{12}$ (Anon., 2023). Using this formula I calculated my moment of inertia as $1.95 \times 10^{-4} \text{ m}^4$

I am now ready to plug data into the equation. Using the values calculated P_{cr} is 441 786 Newtons or 441.786 kilo Newtons

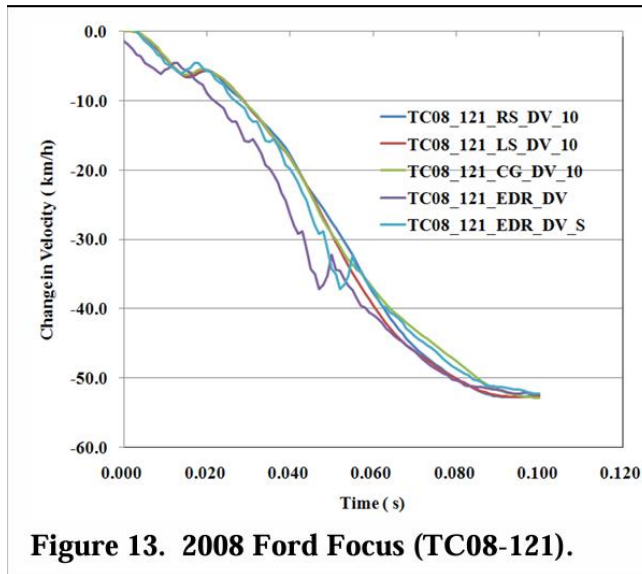


Figure 6- crash pulse data graph

	Test speed (km/h)	EDR	Difference	Difference %
Ford Focus	47.66	46.83	-0.83	-1.77

Figure 7- crash pulse data table

(Comeau, n.d.)

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