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Frontal Crash

Automotive Chassis Systems (ACHA5013)

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1 Introduction

This assignment, part of the "Automotive Chassis Systems" module, aims to explore the historical development of vehicle structures and estimate the fundamental buckling load of a longitudinal in an automotive Body in White (BIW).

1.1 Aims

1. **Analyzing the Evolution of Vehicle Structures:** This involves understanding how vehicle structures have evolved, considering factors like torsion, bending, aerodynamics, and crash requirements. The impact of manufacturing, material advancements, and regulations such as EuroNCAP will also be examined.
2. **Estimating Buckling Load in Frontal Crashes:** Estimating the theoretical fundamental buckling load for a chosen automotive BIW and comparing it to the forces in a typical frontal crash pulse for a similar vehicle.

1.2 Objectives

The goal of this report is to deepen understanding of chassis systems and their impact on vehicle safety and performance as well as the evolution of these systems, while developing analytical and research skills relevant to automotive engineering.

2 Historical Development of Vehicle Structures

This section will discuss the history of vehicle structure development and the various aspects that have been considered and integrated throughout the automotive industry since the early 20th century.

The evolution of vehicles structures is a complex field due to the many variables such as vehicle Dynamics, Material choice and advancements, manufacturing techniques and regulatory requirements such as safety and crashworthiness being important aspects to consider in a modern vehicle design and production process. We will consider various chassis structures used throughout the history of the automotive industry.



Figure 1- Conventional Coachwork frame (https://en.wikipedia.org/wiki/Weymann_Fabric_Bodies)

Figure 1 above shows us a conventional coachwork frame that would have been build by Carpenters during the early 20th century, consisting of a heavy wood such as Ash to make up the frame which was then reinforced by wrought iron brackets.

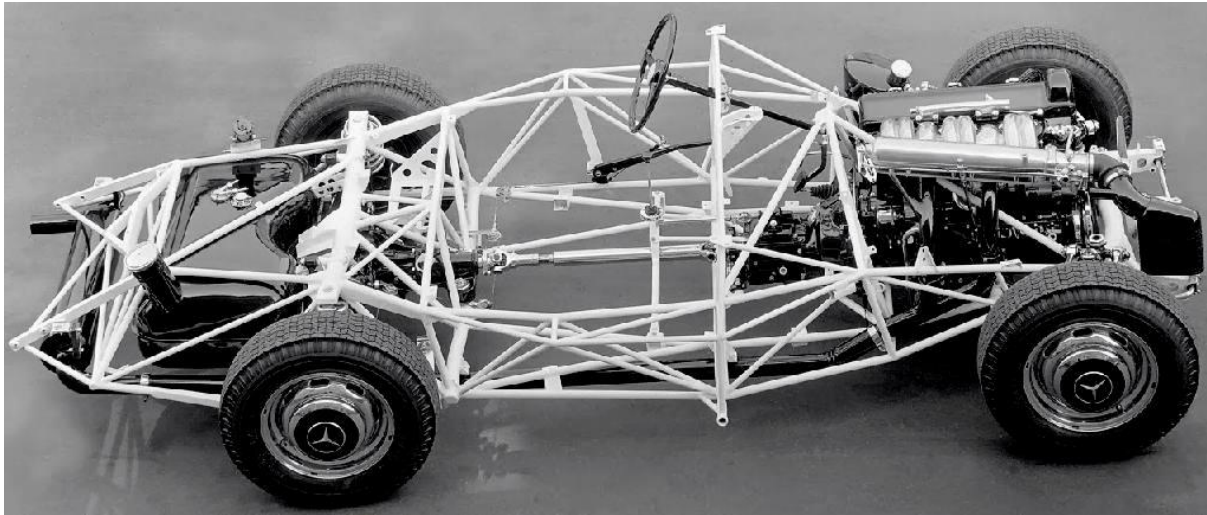


Figure 2 - Space Frame Chassis (<https://discourse.automationgame.com/t/why-would-a-manufacturer-use-a-ladder-frame-in-a-car/26074>)

Figure 2 above shows us a chassis design known as a Space frame, which usually consists of steel tubing that gets welded together to make a structure to house the general components. This became a popular option in the 1950s for vehicles that required a lightweight chassis such as the Mercedes 300SL considered a sports car.

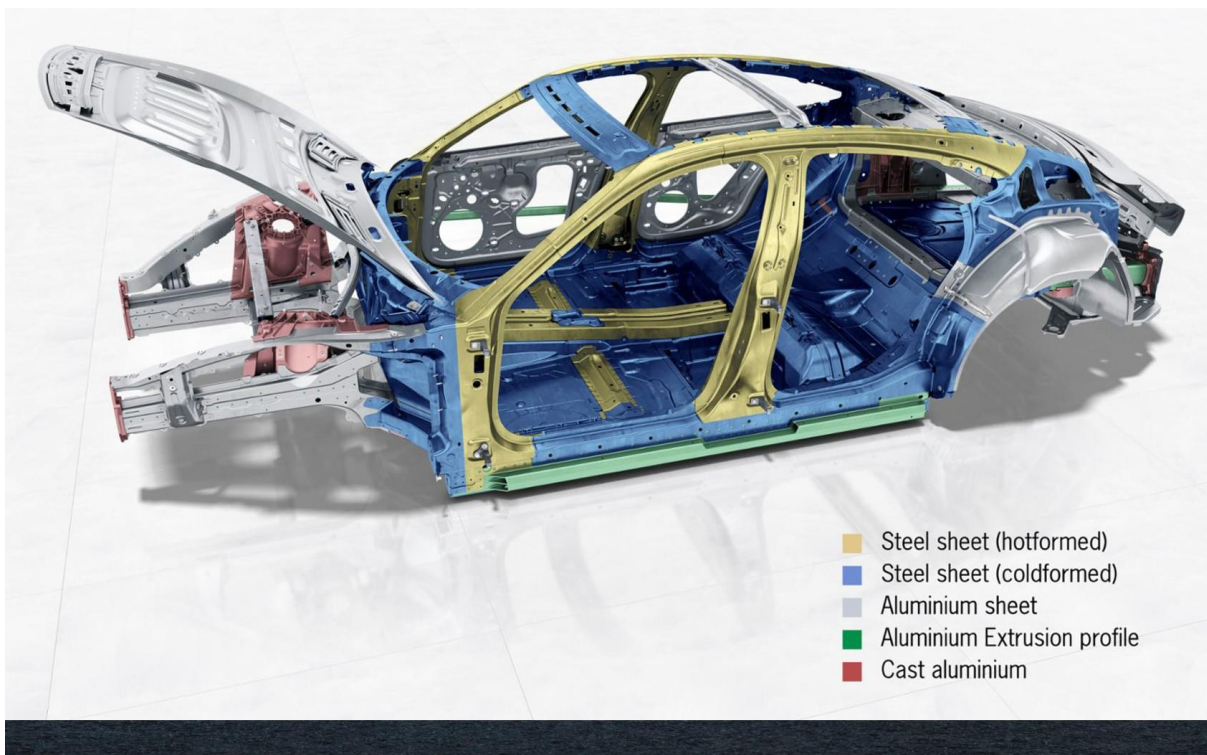


Figure 3 - Unibody Chassis (https://s1.cdn.autoevolution.com/images/news/gallery/here-is-how-the-porsche-taycan-s-unibody-is-made_6.jpg)

Figure 3 above shows us the most common type of chassis structure used in the automotive industry which is the unibody. The body and major chassis and crash structures in a unibody are usually a combination of welding, bonding and moulded joints that make it a single structural element, increases the stiffness of the chassis they are usually made of steel and aluminium which allows a reduction in the overall

weight of the vehicle, enabling a more spacious cabin for the occupants.(Pană and Grigorie, 2018)

2.1 Torsion and Bending

Torsional and Bending rigidity are important aspects when considering a Body in White (BIW) structure (Pine, Lee and Jones, 1999), these forces were not always considered during the early inception of automotive vehicles as the scientific understanding and technical ability to analyse and implement solutions were relatively limited during the early 20th century. Complexities such as material selection, structure, fatigue and stress cycles were not well understood or easily calculated without modern computing and engineering principles that have since been developed.

Vehicles manufactured during the early 20th century were also not subject to higher vehicles speeds and used in less demanding conditions compared to modern vehicles as well as less focus being put onto occupant safety as the main objective was cost affordability and reliability which means Torsional Strength was not considered as in depth.

As engineering knowledge improved and societal factors were taken more into focus, including higher speeds, varied road conditions, and a greater focus on safety and performance, the automotive industry began to place more emphasis on understanding and improving vehicle dynamics, including torsional rigidity and bending resistance, since a chassis consists of multiple cross sections it is important to consider the chassis as one series of multiple cross sections joined together.(Tebby, 2011) This led to the sophisticated, safety-conscious designs we see today.

2.2 Aerodynamics

Aerodynamic considerations have been an increasingly important aspect in the automotive sector from the original designs in the 1920s which were boxy with a large frontal area without considering air resistance and the drag-force being generated. As cars became lighter and faster the effects of air resistance became more apparent resulting in an increased focus on improving aerodynamic performance, the need to manage airflow for stability, cooling and energy efficiency became more critical.

During the modern era of vehicle design, Computer Aided Design (CAD) advancements allowed for more complex and precise testing and simulation of panel shapes leading to lower drag coefficients as well as increasing overall performance by creating downforce.(Othmer, 2014)



Figure 4 - 1920 Dodge Aero and Frontal Profile

Figure 4 is of a 1920 Dodge Touring Cabriolet giving us a visual of the large frontal area of this vehicle as well as the 90-degree surfaces in the direction of travel resulting in a larger drag force.



Figure 5 - Aston Martin Valkyrie

Figure 5 is of the Aston Martin Valkyrie which was manufactured with aerodynamic performance as one of its main criteria, this shows the large complexity difference

between the early era vehicles with the modern era and how aerodynamic performance and understanding has evolved.

2.3 Crash Requirements

The evolution of crash requirements in the automotive industry is a progression of increasing safety standards, technological advancements and an overall improvement in understanding vehicle impacts and the safety of the occupants and any pedestrians. In the earliest days of automotive design there was very little consideration for crash safety as cars were motorized carriages as well as the speed these vehicles would reach was not considered unsafe at the time. Many of the first 'safety' features brought to the sector were usually regarding vehicle operation such as improved braking systems and headlights.

Modern vehicles incorporate a range of safety systems including multiple airbag types which became a part of automotive design in the 1950s. Air bags are a system used to protect the driver and occupants during a potential collision and reduce the risk and seriousness of any injuries that may occur, airbags are constantly undergoing continual improvements in terms of design, material and performance(Nayak *et al.*, 2013).

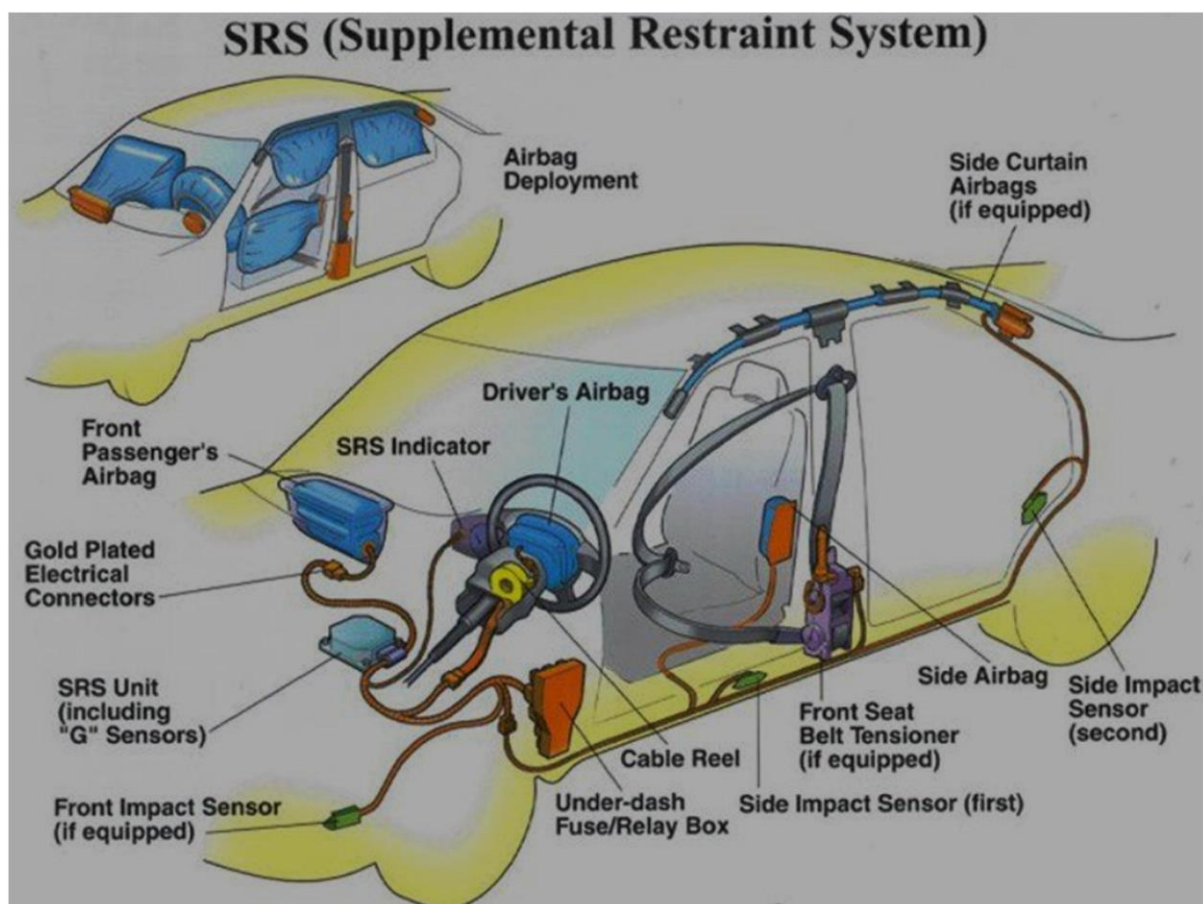


Figure 6 – Airbag system in a vehicle (Samantray and Parashar, 2023)

Figure 6 above shows us a detailed view of the airbag system in a vehicle and the deployment of the systems in a crash. Other safety elements such as the Front Seat Belt Tensioner are included as well as side airbags and the electrical system and sensors involved to detect a collision to deploy these safety systems.

The World Health Organization (WHO) estimate that 1.25 million people die because of road traffic crashes a year and millions more are injured as a result. From the year 2021 they have released their Global Plan for action to improve vehicle safety standards which may result in manufacturers increasing the protection their vehicles provide to the public and occupants.

2.4 Manufacturing and Material Developments

The evolution of the chassis structure of a vehicle over the last century reflects trends in both engineering, materials science and consumer demands. The chassis is the structure that supports all the components and body of the vehicle including all suspension components and the drive chain including the engine. Initial manufacturing and material choices of vehicles once they became predominantly made of steel were ladder frames which were simple and rigid frame structures, they were strong and easy to manufacture but were also heavy and inflexible, they focused on the functionality and durability over the performance and efficiency. Ladder frames are still used in the automotive sector for commercial vehicles such as lorries and vans which rely on being able to transport heavy loads and do not require an agile or performance driven chassis.

During the mid-20th century as technology increased and advancements in design and materials improved, manufacturers began to evolve the ladder frame into more box and X-style frames which increased rigidity but also improved handling. They also increased the overall torsional stiffness and lowered the centre of gravity. Material selection began to broaden with the introduction of Aluminium and steel alloys which further strengthened the chassis whilst simultaneously reducing the overall mass of the components. (Marsh, 2003)

Material development in the automotive sector has been driven by safety needs, performance, sustainability and efficiency in production and implementation. As technology and engineering understanding has evolved, so has the material selection for vehicles in general and specifically the chassis. Steel has been the most widely used material in vehicle chassis design due to its high strength, durability, ease of manufacturing and relatively low cost compared to other metals.

Advancements in materials science has allowed the use of materials such as carbon fibre, aluminium alloy and advanced high strength steels (AHSS) for chassis design. Carbon fibre although more costly is an effective material known for its high stiffness, tensile strength and low weight, it is predominately used for monocoque chassis designs for luxury high performance cars and race cars such as in Formula 1.

As technology continues to improve, manufacturing processes such as 3D printing are beginning to be incorporated into large production of vehicle components,

although this is unlikely to be applied to a structure such as the chassis any time soon, it may allow for additive manufacturing developments.



Figure 7 - Rimac Carbon Chassis (https://hips.hearstapps.com/hmq-prod.s3.amazonaws.com/images/imq-5070-1553101920.jpg?crop=1.00xw:0.752xh;0.0.113xh&resize=1200:*)

Figure 7 shows us a monocoque design of the Rimac C Two which is made of carbon fibre attached to an aluminium box section for a crash structure.

2.5 Regulations and Consumer Testing

Regulations and consumer programmes such as New Car Assessment Program (NCAP) have influenced the design and safety standards of the automotive chassis design and the frontal crash requirements. The regulations primarily concern themselves with reducing fatalities and serious injuries in the result of a collision. This also includes the vehicle safety features, crashworthiness, occupant protection and pedestrian safety.

Various countries and regions have their own regulatory bodies that set their own safety standards for vehicle manufacturers which they must adhere to if they wish to provide their product to that region. Over time regulations have become stricter as a result in part of advancement in technologies and understanding of crash dynamics. This has forced manufacturers to develop stronger chassis designs and safety systems.

NCAP is a service that provides consumers with independent assessments of the safety factors of new vehicles released where crash tests are performed on the vehicle and they are rated on the safety criteria they met; this encourages manufacturers to aim for improves scores which would in turn reflect positively on their product. The desire to achieve high NCAP ratings has driven manufacturers to invest in advanced chassis engineering and materials design, this also includes better energy-absorbing crumple zones, reinforcing the passenger cabin and

implementing advanced safety designs such as autonomous braking, lane correction and impact detection.

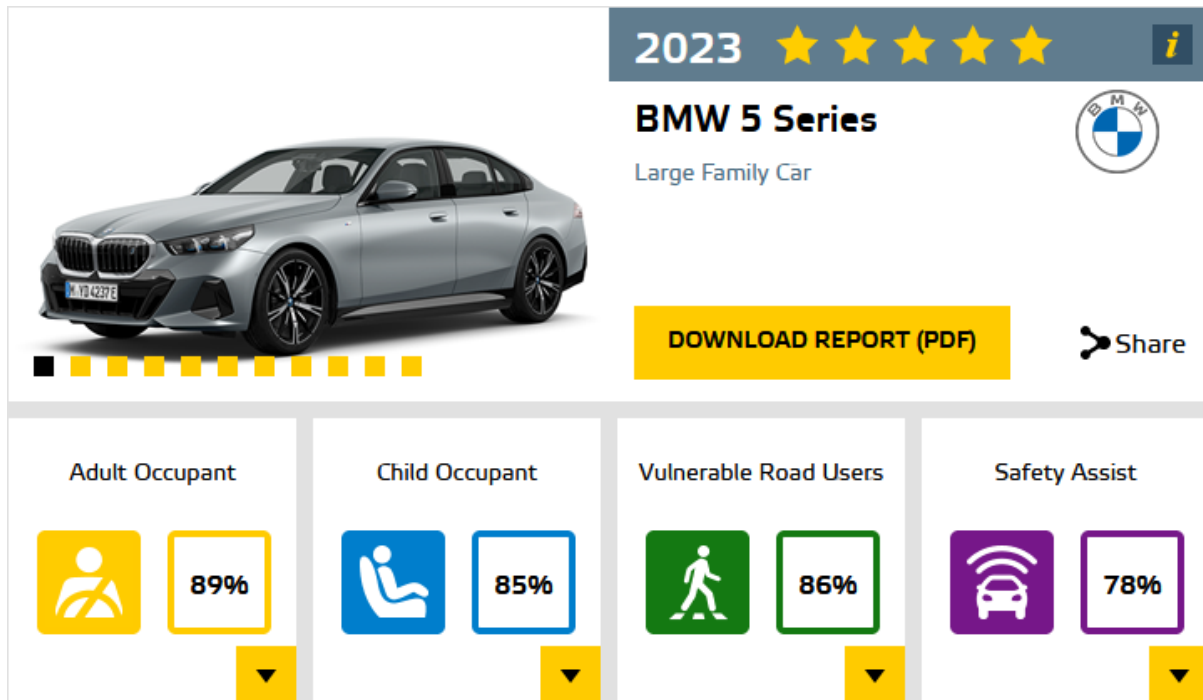


Figure 8 - Euro NCAP BMW 5 Series results (<https://www.euroncap.com/en/results/bmw/5-series/50186>)

Figure 8 above shows the overall scores given in percentage to the BMW 5 series released in 2023, it shows that the vehicle scores highly in all 4 of the tested categories, all of which are performed in crashes and potential road incidents.

Continuously evolving regulations and NCAP testing has led to the development of stronger and safer chassis that can better withstand the forces of a frontal crash, including the materials chosen that can better absorb this energy. The frontal part of the vehicle is designed to crumble in a controlled manner to reduce the force transmitted towards the occupants. Regulations have also led to the standardisation of safety features to protect the occupants in the event of a frontal crash such as airbags, seatbelt pretensioners and even components such as the vehicle seats, which are an important aspect for protection and performance of the safety features. (Wang *et al.*, no date)

2.6 Conclusion

In conclusion, the development of automotive vehicles, particularly in terms of torsional and bending rigidity, aerodynamics, crash requirements, manufacturing, and material advancements displays the continuous improvement and innovation of chassis design. Initially, the industry's focus on cost affordability and reliability overshadowed the importance of torsional strength and aerodynamic efficiency. However, as societal factors like safety, performance, and speed took precedence, so did the complexity of vehicle designs. The evolution from the boxy and drag-prone early vehicles to aerodynamically optimized modern cars, progression in crash safety requirements highlights a commitment to preserving human life, evolving from the rudimentary safety features of early automobiles to the advanced systems seen today. This evolution has been significantly influenced by stringent regulations and consumer safety programs such as NCAP, which have raised the bar for vehicle safety, driving innovation and competition among manufacturers.

As the automotive industry continues to evolve, innovations including further advancements in material science, manufacturing techniques, and safety regulation, reflects the industry's adaptability and continuous drive towards a safer and more sustainable future.

3 Estimation of Fundamental Buckling Load

Using Euler's Buckling Formula $P_{cr} = \frac{\pi^2 EI}{4L^2}$ we will estimate the critical load that the longitudinal fixed section of the chassis structure is subject to.

Where:

- P_{cr} is the critical buckling load.
- E is the Young's Modulus of the material.
- I is the least moment of inertia of the cross section about the axis of buckling.
- 4 is the effective length of the column, which is fixed at one end.
- L is the length of the column

For a general calculation of a beam of a fixed length of steel for a longitudinal support the following parameters have been chosen.

$E = 210\text{GPa}$ (A typical value for steel)

$I = 500 \times 10^{-12} \text{m}^4$

$L = 1.5\text{meters}$

In a typical frontal crash scenario, the forces experienced depend on variables including the speed of the impact, the mass of the vehicle and the stiffness of the design of the vehicle. During a typical NCAP test, typical speeds may range from 35-56km/h for full frontal tests. The crash pulse is the profile of acceleration/deceleration over time of the vehicle, a typical frontal crash pulse might last around 100ms with a peak force occurring early in the crash. The overall shape of the pulse matters in terms of the injury outcome of the passengers as a square wave pulse transfers more energy in a shorter time which results in a higher risk of injury. Optimal crash pulses would be in the form of a sine wave meaning that the occupants would not be subject to a higher force (Teng *et al.*, 2017a).

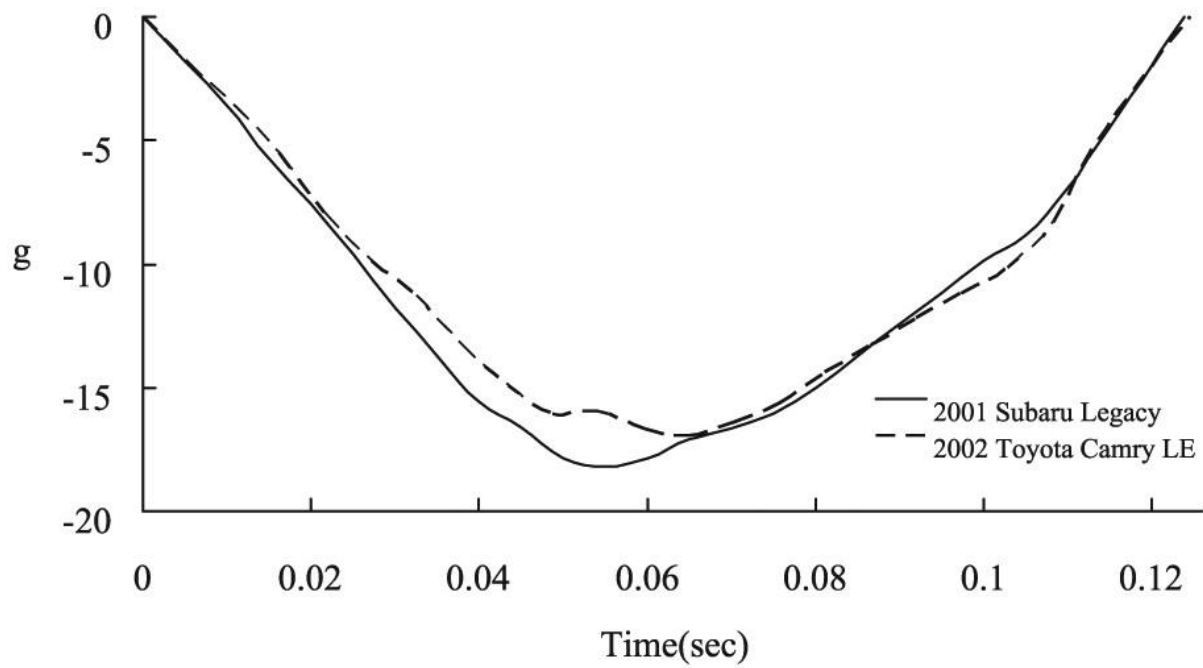


Figure 9 - Buckling load of Subaru Legacy vs Toyota Camry (Teng et al., 2017b)

Figure 9 above is a comparison crash pulse between a 2001 Subaru Legacy and a 2002 Toyota Camry. overall, the graph shows us that whilst both vehicles have similar sinewave pulses, the Legacy is subject to a larger ultimate deceleration than the Camry.

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