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HND/BENG Automotive Engineering

Automotive Chassis Systems

Vehicle Structures: Past, Current and  
Future

ACHA5013

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## Introduction

This report will investigate the development of Vehicle Structure. This will be achieved by looking at examples that will be found through research as demanded by the assignment brief. The examples that will be explored will be from several historic sources along with modern day instances. The report will achieve the requirement laid down by the brief through the completion and documentation of a few tasks:

1. A discussion on how vehicle structures have changed over time and how new technologies may influence vehicle structures in the future.
2. With reference to the previously explored structures the report will discuss crash requirements, manufacturing methods and technologies along with how the materials use for manufacturing have changed over time.
3. The report will assess a given structure in terms of shear loads and torsion through use of the simple structural surfaces method (SSS).
4. Finally discuss the surfaces calculated in the previous task, with a view of assessing any implications that could be involved by improving rear vehicle access.

## Investigation

### Task 1: Historical examples of vehicle structures.

Nicholas Joseph Cugnot was credited with designing and building the first steam-powered car which was developed in 1769 (Seven years before the American Revolution). The maximum speed that this behemoth could do was only up to 4 kmph and it could only run for 15 minutes before there was a need to re-heat and re-pressurise the steam (Britannica, 2019).

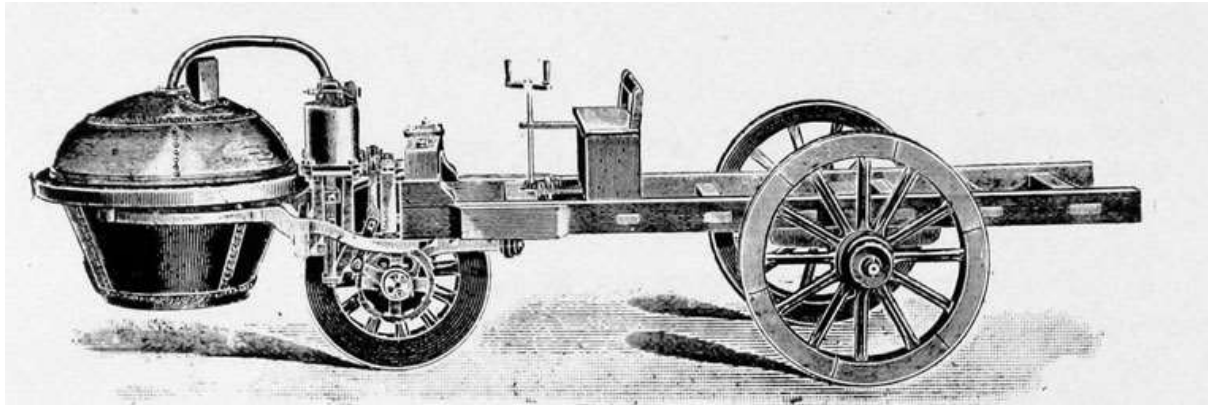


Figure 1: Cugnot Steam Dray (Etching)

The composition of the Cugnot steam dray is as seen below (Supercars.net, 2021) :

|               |                              |
|---------------|------------------------------|
| engine        | 2-Cylinder Steam             |
| position      | Front Transverse             |
| body / frame  | Wooden Frame                 |
| driven wheels | FWD, Conrod on Notched Discs |
| wheel type    | Wooden w/Steel Inserts       |
| f brake size  | mm / in                      |
| r brake size  | mm / in                      |
| gear ratios   | :1                           |
| top speed     | ~4 kph / 2.5 mph             |



Figure 2: Cugnot Steam Dray (photo)

As can be seen in the information above, this vehicle was comprised of a primitive engine (a steam engine) and a chassis made primarily of wood. The vehicle had no recognisable gears or braking system. The vehicle was initially designed to tow artillery guns and was very difficult to steer. The idea behind the vehicle was to replace horses for the transportation of canons. The difference between this behemoth in comparison to horses is that this thing did not get tired when moving heavy artillery. The vehicle weighs about 2 and a half tons. Due to the way the weight is distributed across the vehicle, historical sources state that the vehicle was very unstable which would have made it unsuitable to tow the heavy guns across the rough terrain. While this was not a major success, it is recognisable as an engine driven vehicle and as such is very interesting as an early proof of concept.

This is the first modern engine powered automobile that was patented by Carl Benz (Happian-Smith Julian, 2002). This delicate piece of work was designed back in 1886. This three-wheeled vehicle was also known as the Motorwagen. It runs only three wheels because Benz had not yet developed a four-wheel version of the vehicle (Benz found a solution to steering four wheeled vehicles in 1893) the Motorwagen had a top of 16kmph and had a curbed weight of 265kg (Daimler, 2021).

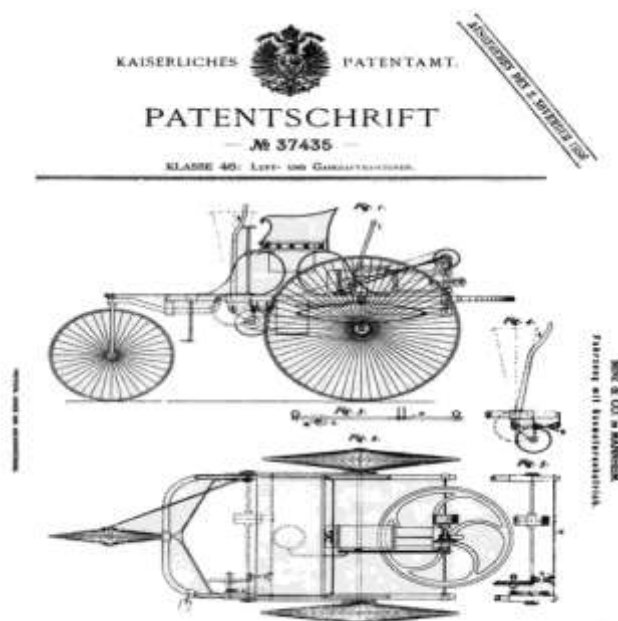


Figure 3 The original patent of the Motorwagen (Daimler, 2021)



Figure 4 The Motorwagen photograph (Daimler, 2021)

The composition of the Motorwagen is as seen below (Mercedes-Benz AG, 2021) :

#### Chassis and drivetrain

|                            |                                                                                                                                                                          |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Frame design               | steel-tube frame                                                                                                                                                         |
| Front-wheel suspension     | 1 front wheel in steering fork                                                                                                                                           |
| Rear-wheel suspension      | rigid axle                                                                                                                                                               |
| Front springs              | not fitted                                                                                                                                                               |
| Rear springs               | full-elliptic springs                                                                                                                                                    |
| Steering                   | rack-and-pinion steering, steering crank in centre of vehicle                                                                                                            |
| Brake system (foot brake)  | not fitted                                                                                                                                                               |
| Parking brake (hand brake) | band brake, acting on countershaft belt pulley                                                                                                                           |
| Wheels                     | wire-spoke wheels; front 730 mm, rear 1125 mm                                                                                                                            |
| Tires                      | solid-rubber tyres front and rear                                                                                                                                        |
| Driven wheels              | rear wheels                                                                                                                                                              |
| Drivetrain                 | 1 flat belt from the engine to the countershaft with loose- and fixed-pulley set and integrated differential: one chain from the countershaft to each of the rear wheels |

This vehicle has a rear mounted engine and in structure is shaped more like a large tricycle than a modern car. One of the reasons of this design is (as previously mentioned), the fact that Carl Benz had not at this point developed an effective means of steering a four-wheeled vehicle. Despite its strange design this example shares many characteristics with modern cars such as petrol driven engine and braking system.

The image below (figure 5) is the Ford Model T which was designed by Henry Ford and was sometimes referred to as a Tin Lizzy (History.com, 2021). These vehicles were designed to be both mass-produced and affordable. They were in production by the Ford factories between 1908 and 1927. Unlike the previous examples in this report, The Model T as seen below is immediately recognisable as a modern style automobile.

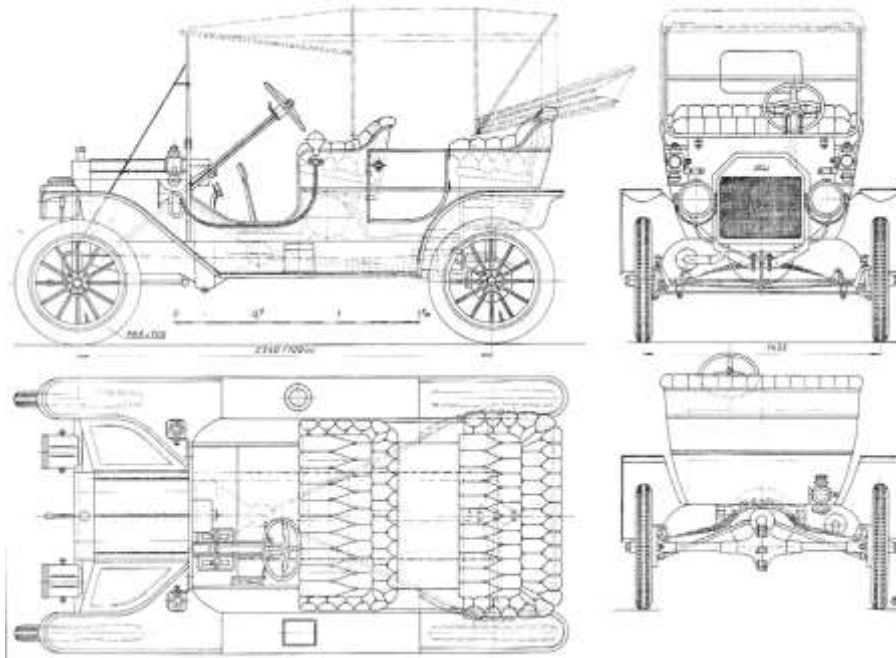


Figure 5 Henry Ford's Model T (Diagram) (DaCosta Samuel, 2021)

The composition of the Model T is as seen below (Specs, 2021) :

|                                               |                                      |
|-----------------------------------------------|--------------------------------------|
| Engine type - Number of cylinders:            | Inline 4                             |
| Engine Code:                                  | -                                    |
| Fuel type:                                    | Petrol                               |
| Fuel System:                                  | 1 Holley carb                        |
| Coolant:                                      | Water                                |
| Engine Alignment:                             | Longitudinal                         |
| Engine size - Displacement - Engine capacity: | 2878 cm <sup>3</sup> or 175.6 cu-in  |
| Bore x Stroke:                                | 95.00 x 101.50 mm 3.74 x 3.98 inches |
| Number of valves:                             | 8 Valves                             |
| Aspiration:                                   | N/A                                  |
| Maximum power - Output - Horsepower:          | 20 PS or 20 bhp or 15 kW @ 1800 rpm  |
| Maximum torque:                               | - Nm or - lb. Ft @ 1800 rpm          |
| Drive wheels - Traction - Drivetrain:         | RWD                                  |
| Transmission Gearbox - Number of speeds:      | 2 speed Manual                       |

|                            |                                       |
|----------------------------|---------------------------------------|
| body:                      | Sedan                                 |
| Num. of Doors:             | 4                                     |
| Wheelbase:                 | 255.3 cm or 100.51 inches             |
| Length:                    | 340.4 cm or 134.02 inches             |
| Width:                     | 167.6 cm or 65.98 inches              |
| Height:                    | - cm or - inches                      |
| Front Axle:                | 146.7 cm or 57.76 inches              |
| Rear Axle:                 | 146.7 cm or 57.76 inches              |
| Curb Weight:               | 700 kg OR 1543 lbs                    |
| Weight-Power Output Ratio: | 35 kg/hp                              |
| Front Suspension:          | Transverse leaf spring. De Dion axle. |
| Rear Suspension:           | Transverse leaf spring. De Dion axle. |

|                                           |                   |
|-------------------------------------------|-------------------|
| Top Speed:                                | 68 km/h or 42 Mph |
| Acceleration 0 to 60 mph (0 to 96 Km/h):  | 1.00 s            |
| Acceleration 0 to 100 km/h (0 to 62 mph): | - s               |



*Figure 6 Model T Photo* (Branch Jon, 2018)

Despite this vehicle looking very delicate, the chassis itself is deceptively strong. It was made of an alloy comprised of vanadium (atomic number 23, hard solid malleable metal) and steel (Happian-Smith Julian, 2002). It is estimated that approximately 15 million cars were produced (this was the longest run of production of any car until mass production of the Volkswagen beetle in 1972 (History.com, 2021)).

The Volkswagen beetle was designed by Ferdinand Porsche (the founder of the Porsche car company) in 1938 under instruction by Adolf Hitler to design and produce a car for the people that could be mass produced and affordable (much the same as the ideas behind Ford's Model T).

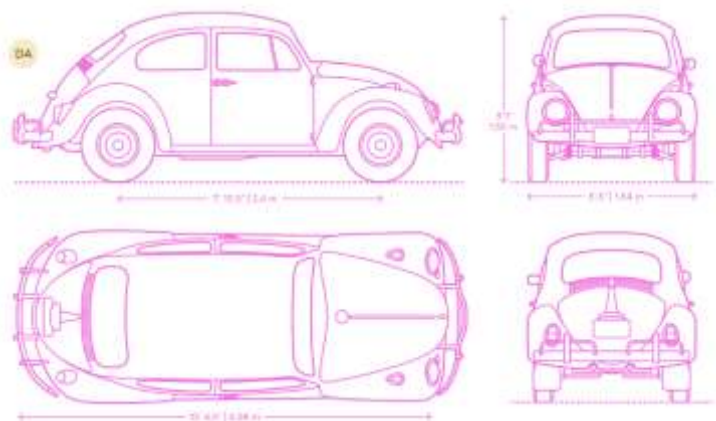


Figure 7 Blueprint of Volkswagen Beetle (Dimension.com, 2021)

The composition of the Volkswagen Beetle is as seen below (Conceptcarz.com, 2021):

## Features

|                              |                       |
|------------------------------|-----------------------|
| Engine Location:             | Rear                  |
| Drive Type:                  | Rear Wheel            |
| Body / Chassis:              | Steel unibody         |
| Production Years for Series: | 1938 - 1980           |
| Price:                       | \$1,480               |
| Weight:                      | 1600 lbs   725.748 kg |

## Performance

|            |                                 |
|------------|---------------------------------|
| Top Speed: | 60 mph   96.54 km/h (estimated) |
|------------|---------------------------------|

## Power

|               |          |
|---------------|----------|
| Transmission: | 4 Manual |
|---------------|----------|

## Production Figures

|                                       |        |
|---------------------------------------|--------|
| Total Volkswagen Production for 1943: | 13,904 |
| 1943 Volkswagen KdF-Wagen             |        |



Figure 8 (Left) Volkswagen Beetle 1943 photo (Right) Volkswagen Beetle 2019 photo (Conceptcarz.com, 2021) (U.S.News.com, 2021)

The Volkswagen beetle as shown in the photograph above is an earlier example of its design (1943). The Volkswagen organisation company continued to produce the beetle vehicle design through a series of different models and ranges until the year 2019 (so that is 80 years in the making which is astonishing). The Volkswagen beetle 2019 model was also known as the final edition because production for the beetle was scheduled to cease in September of this year (Locker Melissa, 2021). The newer volkswagen beetle as seen in the photo (above right) switched the engine position from the rear to the front of the vehicle (like most other modern cars). The Volkswagen beetle is an excellent example of how car design structure can show longevity despite changes in culture and markets.

Most modern cars have a similar structure, the diagram below illustrates some of the key components of a generic car structure.

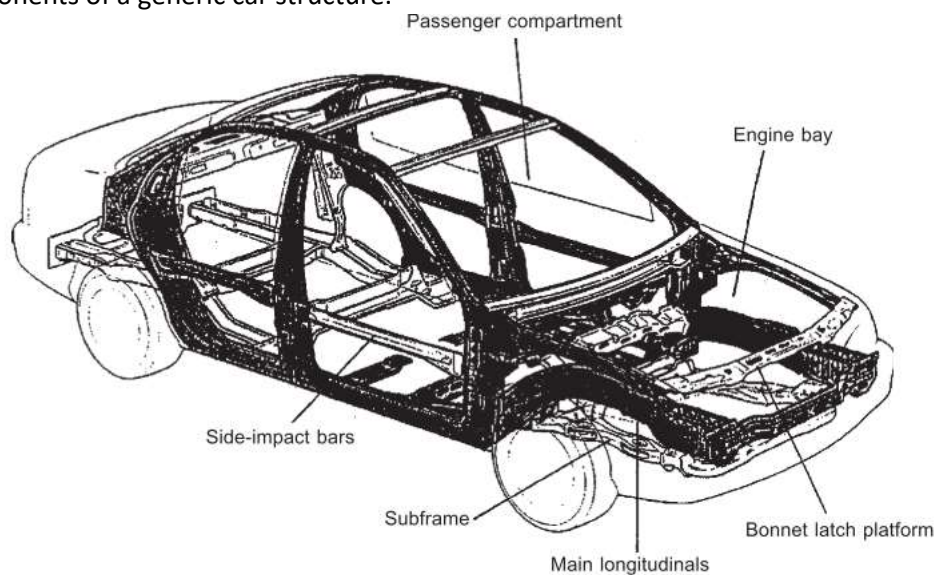


Figure 9 diagram of the modern structure car (Happian-Smith Julian, 2002)

## Task 2: Further notes on the examples

It is estimated that the invention of the motor car is responsible for more injuries and fatalities than any other invention on a year-to-year basis, but it was not until the 1950's and 1960's that much emphasis was made on safety design.

A dangerous element on pre-second world war cars was the steering column which was positioned in a way that it pointed directly at the heart of the driver (this could stab into the driver in the event of an impact). This concern was later mitigated in the 1960's with the invention of collapsing steering columns (This feature became a legal requirement in many countries).

A safety precaution that most readers would recognise is the seat or safety belt. These were first offered in 1950 by the Nash company that did not become legally required even for front seats for many years. It was many years after regulations on fitting sit belts to the front seats of cars became law that it became mandatory to have rear seat belts.

Air bags were first introduced in America where research began in the 1960 and were later sent to other countries in later years. Some key developments relating to airbags include (Wilson Paul, 2017):

- In 1964 (in Japan), Yasuzaburou Kobori developed "the airbag safety net". This was patented in 14 countries but was not implemented wide scale within his lifetime (Kobori died in 1975)
- In 1967, there was a breakthrough in the field of crash detection which made safe deployment of safe airbags a possibility. This development was not directly an innovation in airbag technology but rather a method in detecting if the vehicle had been involved in a collision. The "mechanically based ball in a tube" was comprised of a steel ball, a magnet and an electro-mechanical sensor which would trigger the airbag. This device was invented by Allen K Breed.
- In 1971, the Ford Company installed airbags as an experiment.
- In 1973, General Motors fitted airbags to their Chevrolet models, but these vehicles were only sold to the US government.
- Also, in 1973, the Oldsmobile Toronado company was the first automobile company to introduce airbags for passengers.

There are many types of airbags and this report will not go into specific details on each, but the main categories include:

1. Side Airbags
2. Side Torso Airbags
3. Side Tubular Airbags (Curtain Airbags)
4. Knee Airbags
5. Rear Curtain Airbags
6. Seat Cushion Airbags
7. Centre Airbags
8. Seatbelt Airbags
9. Pedestrian Airbags

Early motor vehicles were produced in a similar way to horse-drawn carts and carriages. This is to say that each vehicle was built on a one-to-one basis. This resulted in a situation whereby two vehicles built the same design may have subtle differences on a very small level. Resulting in two products that would look identical not necessarily having interchangeable parts. This was due to hand tooling of the various parts as opposed to the precision engineering that use of technology could produce on a production line (Happian-Smith Julian, 2002).

The production line became a reality and is key to mass production. One of the key factors indicated through task one is the drive to produce vehicles on a large scale and at an affordable cost (Ford Model T and the Volkswagen beetle are excellent examples of this).

Materials used in engineering have changed dramatically within the time frame in which cars have existed (the reader may note that some of the early examples in task one relies on primitive materials such as wood for their chassis and components). These newly developed materials have allowed innovations in car design including body work, engines fuel supply and electronic devices. Some of these materials include (Happian-Smith Julian, 2002):

- Metals and alloys: some metals are rarer than others and as such tend to be used for very specific purposes (for example, the creation of components of magnets). Other metals such as aluminium and iron are abundant in the earth's crust as such are quite often used or as part of an alloy. Low carbon steel is strong and easy to manipulate and as such is quite often used for body work and wheels with high carbon steel being used for load bearing surfaces.
- Plastics and polymer: both natural and synthetic polymers are used in the creation of components in vehicles. Natural polymers include items such as natural rubber. The first synthetic polymers were created approximately 100 years ago and there are now thirty different categories of polymeric materials that are commonly used (many of these are used in vehicle engineering and can be used for body work or bumpers). Most polymers are now derived from oil which being a non-renewable resource which will have an environmental impact.
- Ceramics and glasses: these materials are very brittle and as such do not tend to be used for structural reasons in vehicle design but due to their resistance to corrosion, they can be beneficial to the vehicle's engine components, an example being, their piston heads and cylinders of a diesel engine.
- Composite materials: This is where two or more materials are combined in order to make the most of the desirable qualities of each (the outcome is that the composite will be more favourable for a function than one of the materials within it acting on its own).

### Task 3: Assessment of van panels using SSS methods

The image below (figure 10) illustrates a van in torsion along with its associated specifications. The purpose of this task will use the Simple structural surface method in order to assess the vehicle and calculate to shear loads of each panel.

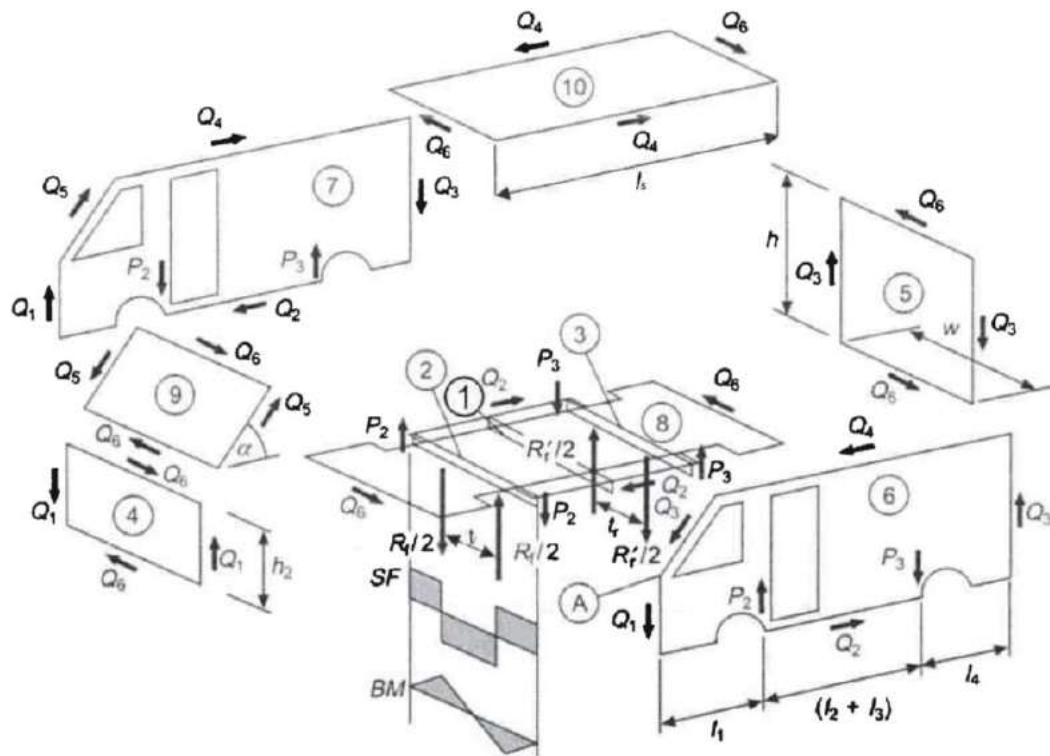


Figure 10 Van structure separated into panels (Wronska, 2021)

$w=2\text{m}$   
 $h=2\text{m}$   
 $h_2=1\text{m}$   
 $l_1=2\text{m}$   
 $l_2+l_3=3\text{m}$   
 $l_4=1\text{m}$   
 $l_5=3\text{m}$   
 Overall weight = 3000kg  
 Weight distribution = 50:50  
 $t_f=1.5\text{m}$   
 $t_r=1.5\text{m}$   
 $\alpha=45^\circ$   
 $R_f=R_r=5\text{kN}$

Figure 11 Figures for calculating the panels

The first stage of the calculation is to work out P2 and P3 which are the vertical loads acting on the vehicle as see in the diagram (figure 10), this was done using the following formulas:

$$P_2 = \frac{R_f t_f}{2w} = \frac{5000(1.5)}{2(2)} = 1875 \text{ N}$$

$$P_3 = \frac{R_r t_r}{2w} = \frac{5000(1.5)}{2(2)} = 1875 \text{ N}$$

The next stage is to calculate the Q values, The Q value represents the shear loads at the edges of each panels. These values must be calculated in the order seen below (Q<sub>6</sub> must be calculated first as it should be use in all further calculations):

$$Q_6, Q_1, Q_2, Q_3, Q_4, Q_5$$

$$Q_6 = \frac{W[P_3(L_1+L_2+L_3)-P_2h_1]}{h_1(l_1+l_2+l_3+l_4)+l_5(h_1-h_2)+h_2(l_1+l_2+l_3+l_4)} = \frac{2[1875(2+3)-1875(2)]}{2(2+3+1)+3(2-1)+1(2+3+1)} = 536 \text{ N}$$

$$Q_1 = \frac{Q_6 h_2}{w} = \frac{536(1)}{2} = 268 \text{ N}$$

$$Q_2 = \frac{Q_6(l_1+l_2+l_3+l_4)}{w} = \frac{536(6)}{2} = 1608 \text{ N}$$

$$Q_3 = \frac{Q_6 h_1}{w} = \frac{536(2)}{2} = 536 \text{ N}$$

$$Q_4 = \frac{Q_6 l_5}{w} = \frac{536(5)}{2} = 804 \text{ N}$$

$$Q_5 = \frac{Q_6(h_1-h_2)}{w \sin \alpha} = \frac{536(2-1)}{2 \sin(45)} = 379 \text{ N}$$

The torsion then needs to be calculated to consider the torque going into the vehicle:

$$T = P_2 w = 1875 \times 2 = 3750 \text{ N/m}$$

$$\tau = F/A = \frac{804}{3(2(10^{-3}))} = 0.134 \text{ MPa}$$

The next stage is to work out the von-mises stress, the values of sigma 1 and 3 are set as positive and negative tau from the previous calculation (there are no factors other than shear on the roof panel of the van), this will produce shear stress from the shear forces. The von-mises value can be used when assessing whether a material is strong enough not to distort under the anticipated stress:

$$\sigma_1 = 0.134, \sigma_2 = 0, \sigma_3 = -0.134$$

$$\sigma_v = \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

$$\sigma_v = \sqrt{(0.134 - 0)^2 + (0 - (-0.134))^2 + (-0.134 - (+0.134))^2}$$

$$\sigma_v = 0.328 \text{ MPa}$$

If this value was compared to the materials yield strength (if this case, the value for 2mm steel) and it turned out to be larger than of the two values, then the buckling of the structure could be expected. The tensile yield strength of steel is approximately 350MPa (although this figure can vary depending on the composition of the steel alloy, for example, the amount of carbon in the steel (MatWeb, 2021)).

## Task 4

The van as shown in figure 10 is a rigid structure with all the stress being within the tolerance of the material, but the only major stress can be expected to be seen above and below the side doors in panel 6 and 7 and the areas corresponding to the load being applied ( $P_2$  and  $P_3$ ). If panel 5 were to be removed to create a larger access area for the rear of the van,  $Q_6$  and  $Q_3$  would no longer exist and as such no shear loads could be transferred.

It is because the back panel is no longer there, the remaining panels are all acting in bending rather than sheer and because of this the deformation is exaggerated particularly towards the rear of the van. The result of this deformation and change to the distribution of stress is that most panels will now have planes of weakness where the strain will now exceed the tolerance of the vehicle. This could result in buckling across the roof of failures at the joint at the edges of the panels (all edges marked as Q's).

## Conclusion

The report investigated various historical milestones in vehicle development looking into the following key areas:

- Materials used
- Chassis shapes
- Manufacturing processes

The report found out that there have been major breakthroughs through the course of history and because of it, Mankind can make use of this technology in a much safer and more sustainable way.

The second part of this report investigated a specific case study by applying SSS to a generic van structure. The stresses were calculated, and it was observed that removal of the back panel would have a negative affect on the vehicle structurally.

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Wronska, M., 2021. APPENDIX GA36b LEVEL 5 ASSESSMENT SPECIFICATION 11.