



Vehicle Structures

Asad Naqvi | Automotive Chassis Systems | 31/03/21

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Introduction

This report will look into the history of vehicle chassis structures and how they have been developed and improved since cars were invented. The report will look into frame-on-body (ladder), backbone tube chassis, space frame and unibody chassis types. The advantages and disadvantages of the respective chassis types will also be laid out as well as crash requirements, manufacturing technology along with developments in materials will also be researched. The simple structural surfaces (SSS) method will be used to calculate the shear loads on a van consisting of 10 panels. The report will also discuss how current chassis structures are likely to change as internal combustion engine vehicles are phased out for electric.

Chassis Structures

BODY ON FRAME

Figure 1 – Ladder frame



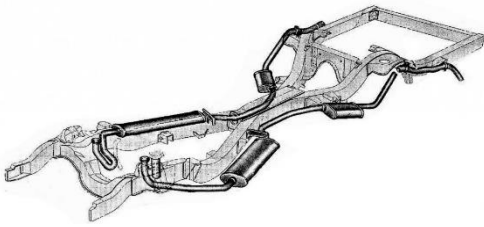
When vehicle mass production took place in the 1920s, the choice of chassis type was limited to 'body-on-frame', which is still in use to this day for its inherent ease of manufacturing due to its simple design. The body on the frame is often called 'ladder' chassis consisting of two rails with cross members connecting both sides of the rails, which increases the torsional stiffness. A century ago, the car manufacturing industry was split into two; companies were either producing the frames or the body; however, the mounting method was universal, which consisted of semi-elliptic springs on the beam axle. Some of the earlier body designs were coach built out of timber by the same hands that made the coaches for horses; these designs have inherently low stiffness and torsion, resulting in a high flexibility. In the 1920s body structures were made to be flexible. The bodies consisted of flexible metal joints and flexible outer panels.

These wooden bodies were placed on a stiff frame in comparison, a lot of braking forces were passed through the body and even a low-speed crashes could prove fatal, or damage the vehicle beyond repair, having needed another body as the frame would still be usable if its not damaged too much. As separate companies manufactured the body and frame, it allowed the body manufacturers to experiment with different designs without major structural alterations illustrating one of its defining features which is its ability to support different body shapes on the same frame and due to its practicality, ladder frames are used on military trucks as a standard. This allows for cost-cutting, and as the vehicles are expected to cross rough terrain. One of the benefits of advantages of the body on frame is that it offers greater twisting resistance, the torsion on the side rails acted on the cross members and the torsion in the cross members acted on the side beams as a bending force.

As demand for vehicles increased, coach manufacturers could no longer keep up as they were hand-building the bodies. In the 1930s body manufacturers started using steel to create the bodies. The sheet steel would be pressed into a shape and held together by way of welding or riveting. The body-on-frame chassis type has many benefits, and because of those exact benefits, it also has drawbacks. Ladder frame vehicles have decreased handling and road grip characteristics due to high torsion resistance, and though they are great for off-road vehicles, it also produces a rougher ride. The chassis' overall design is heavier compared to 'unibody' as well, resulting in poor fuel economy. Body-on-frame scores lower on passenger safety and lack crumple zones that absorb kinetic energy during crashes.

CRUCIFORM FRAME

Figure 2 – cruciform



Also known as x-frame, this type of chassis was first introduced in 1957 on vehicles like the Cadillac Eldorado Brougham. This type of frame is again similar to ladder frames; however, the new frame decreased the vehicle's overall height by use of deep floor

wells as it was not hindered by the side beams like on a ladder-type chassis. Like the backbone chassis, the x-frame also lacks any side impact protection hence it does not see use in passenger vehicles.

BACKBONE CHASSIS

Figure 3 - Tatra 11

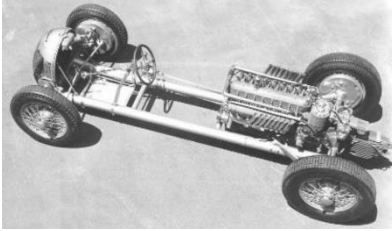


The backbone chassis was first created in 1921 by Hans Ledwinka for the Tatra-11 car. This type of chassis consists of a long tube connecting the front and back axles. The backbone chassis lacks any other structure. Thus, it has no side

impact protection, and it is expected that the car's rigid body will provide the torsion resistance needed. The systems is quite reliable, they can operate off-road with ease as the driveshaft and other essential bits are covered with thick outer tube; however, the manufacturing process is costly and complicated, just like any serious repairs. This type of chassis has been used in the famous DeLorean DMC-12, Lotus Elan and Tatra-11&26. The system is inherently modular and allows for 2-8 axle vehicle, given that a different wheelbase is used. VW also incorporated a backbone into their VW Beetle chassis to increase overall stiffness.

TWIN-TUBE

Figure 4 – twin tube auto union



This type of chassis is very similar to backbone chassis, and this was first introduced in the 1930s and saw use on specialist racing vehicles like the Auto union racing car along with Ferrari and Jaguar in the 50s. The chassis has twin beams in parallel, connecting the front axle to the back. This frame's design proved cheap and straightforward to manufacture; however, the design lacks the same torsion resistance as a ladder frame and is best suited for light motorsport activity.

TRIANGULATED TUBE STRUCTURE

Figure 5 – triangulated backbone



Backbone chassis can also be made using triangulated tubes. These tubes surround the body of the car and in case of a large open cockpit the torsion stiffness will be low, this is resolved by way of boxing in the transmission tunnel. This method of chassis construction is complicated when compared to ladder type, therefore its application is seen in low volume production cars like the TVR and Caterham.

PLATFORM CHASSIS

Figure 6 – Renault 4 platform chassis

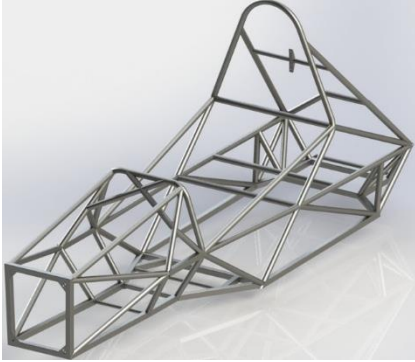


Also known as 'punt' chassis, it is manufactured as a flat platform using sheet metal, on which other components sit. This type of chassis is best suited for small cars. The chassis length is dictated by the length between the wheels. It was initially developed in the 30s, it took inspiration from the ladder and cruciform type chassis. As manufacturing is similar between the body-on-frame and punt chassis having both use pressed steel panels, the body is bolted onto the punt chassis making the two separate units capable of being taken apart. The punt chassis design inherently lacks structural rigidity required thus it is common that a backbone or a perimeter frame

is used to increase rigidity and torsional stiffness of the car. Punt chassis has seen use in the VW beetle, Renault 4 and Lotus Elise.

SPACE FRAME

Figure 7 – space frame



The first true space frame chassis also known as perimeter frame chassis was developed in the late 1930s by Buckminster Fuller and William Stout. Spaceframe has three dimensions (1) length, (2) breadth (3) depth, unlike its counterparts that only consider the first two. Considering depth as well, it has allowed for significant gains in bending resistance and overall chassis stiffness. All planes in the frame are triangulated to produce sufficient rigidity. The tubular design inherently produces high strength as all forces acting on the frame are either tension or compression. One of the major drawbacks of spaceframe is that it reduces access to driver and engine bay, making quick repairs or getting out of the vehicle a little difficult compared to unibody, to overcome this issue, some spaceframes' have sections that are held together using pin-joints, these sections are removable allowing increased access to driver and engine bay for maintenance.

UNIBODY

Figure 8 – unibody



Unibody vehicles combine the frame and the body to produce a single structure. This is done by way of casting entire sections as well as welding panels together. The result is a design makes the whole car a load carrying unit making it responsible for all forces acting on the vehicle when driving along with passenger and cargo loads. Unibody design requires parts like frame rails, rocker panels, pillars and floor pan all welded together in order to produce the necessary structural strength, spaceframe is similar in this regard however, the difference is, spaceframe does not require outer panels to increase overall strength of frame and body. Earlier designs were made using steel, however the overall weight of the unibody proved to be too heavy which resulted in poor fuel economy. This led manufacturers to explore different materials. As aluminum has superior weight to strength ratio, Audi implemented this into their A2 and A8 models and claimed that the frame is 40% lighter and 40% stiffer compared to a steel counterpart

Future of vehicle structure

As all manufacturers are phasing out internal combustion engines for electric power, vehicles' design can be radically changed. Passenger cars of the near future will have excellent passenger safety ratings. There is no engine and other components that can be crushable during impact; the introduction of electric cars will make designing a safer car much more straightforward. The extra space will allow for extra measures to reduce deceleration forces being imparted on the occupants. The front crumple zone can be made more prominent with other measures that will strengthen the overall structure. Manufacturing technology will be improved incrementally as a unibody; punt chassis types still offer excellent protection and are easy to manufacture. These chassis types will be used in the future unless a radically new way of producing cars on a mass scale is developed. 3D printing entire bodies is currently possible; however, this type of manufacturing will be costly and will not support mass production in its current state. Companies will need to invest in the development of this method.

Crash Requirements

'Euro NCAP' 1997 is a consumer vehicle crash testing procedure. The testing consists of impact sensors, audio and video evidence and a 95% percentile adult dummy inside the vehicle. It is designed to produce a real offset impact and observe the damage done to the vehicle and its dummy occupants and then give it a rating. One of the only regulations before NCAP was to ensure that the steering wheel did not intrude more than 12 inches towards the driver seat, and all prior crash test procedures involved only full-width impacts.

NCAP TESTS

Offset Frontal impact

Frontal impact crashes are responsible for more deaths and serious injury than any other type of crash. Most frontal crashes involve 2 cars driving towards each other at moderate speeds. Assuming the vehicle is a mid-size family car, the test will involve adult dummies in the front and child dummies in restraints in the back seats. The car reaches 50km/h hitting a deformable barrier mounted on a 1400kg trolley and travelling at 50km/h. Using the THOR-50M test device, observing the deceleration forces imparted on the test dummies is possible.

- Aspects assessed

in order to improve occupant safety, it is necessary to direct forces from the crash to part so the vehicle where that energy is absorbed. The front crumple zone is expected to deform in a controlled way and ensuring that the passenger cabin deforms as little as possible whilst controlling the amount of deceleration force imparted on the occupants.

Side Impact

Side impact collisions are the second biggest cause of death and severe injury. A deformable barrier is mounted on a trolley to carry out the test and is accelerated to 60km/h. As mentioned above section, medium size car with adults and children size dummies. This test is carried out to ensure that there is enough protection on critical body sections, leading to manufacturers paying close attention to the strength of the pillar between the doors.

Rear impact (whiplash)

Rear impacts, even at low speeds, can cause the spine to distort, resulting in long-lasting and hard to treat pain and discomfort. Whiplash crashes are the least likely to cause death; however, serious injury can be caused. This test is designed to increase knowledge on the geometry necessary to prevent serious injury to the occupants.

MANUFACTURING TECHNOLOGY

In the early stages of vehicle manufacturing, bodies were made by hand by coach builders and consisted of wood and fabric held together by bolts however as to make the cars safer metal made up majority of the vehicle in the 1920-30s.

One of the earlier manufacturing methods called 'pressing' was used to shape all the applicable parts of a vehicle like the outer panels and was used to form the unibody chassis. This method was cost effective and allowed for mass production, however, the major drawback with pressing is that corners and edges of panels were thinner than the surface. This led to a decrease in the structural integrity of the panels, this problem was overcome by use of thicker sheet metal panels, but this came with increased weight. Manufacturers overcome this by developing the 'hydro-form' technique which is essentially thin tubes placed in a die which uses a high-pressure fluid which expands the tubes into the desired shape.

Die casting is also another method that is used in the automotive industry used to create i.e. engine block. This method can prove to be costly if production is low or when trying to keep within tight tolerances, but the method produces highly accurate and durable components.

materials

The most important factor of vehicle construction is the materials it's composed of. Though almost any material can be used to build a vehicle, not all will be able to produce necessary torsion and bending resistance. Materials considered for creating a frame and body will need to be light weight to improve fuel economy, the materials life cycle and recyclability will also be considered along with cost effectiveness.

STEEL

Steel is one of the most abundant materials in the automotive industry due to its high strength and stiffness characteristics and its ability to absorb kinetic energy during crashes. Steel has been used to create bodies and frames of vehicles since the 1900s and due to technological advancements, steel has become lighter and stronger over its earlier steel alloys.

ALUMINIUM

Compared to steel, aluminium has a high strength to weight ratio with excellent corrosion resistance and energy absorption characteristics, therefore use of this metal has steadily increased as tighter regulations have forced manufactures to reduce emissions via improved fuel economy and one of the most efficient ways to do this is to reduce the overall weight of the frame by using AL over steel. Passenger cars mainly use steel however, AL substitution for components and panels are being incorporated to meet EU regulations. High end sports cars like the Audi R8 and Audi A8 utilize fully aluminium frames to increase performance and fuel economy.

MAGNESIUM

Magnesium, like aluminium is a lightweight metal being increasingly utilized and used as a substitute for heavier metals like steel in the automotive industry. Components made of magnesium can be 33% lighter than aluminium and up to 75% lighter than steel. Magnesium also possess better machining characteristics, has better die life and solidifies faster compared to aluminium however, unlike AL, Mg is not corrosion resistant which limits its use on the outside of a vehicle where it will be exposed to the environment, to overcome this, magnesium alloys or corrosion resistance coatings can be used on components. Magnesium also has the same tensile strength as AL making it the perfect substitute as it will result in weight saving.

CARBON FIBER EPOXY COMPOSITE

The motorsport industry has increasingly used carbon fiber epoxy composites like Kevlar as the material offers high strength, low weight relative to its size and thickness. As these composites are based off plastic, they also have excellent corrosion and chemical resistance. The composites offer better molding characteristics than metal and is used to manufacture the necessary outer monocoque panels required for race vehicles.

Van In torsion

By using the Simple structural surfaces (SSS) method, shear and torsional loads will be calculated for a van. Equations used and calculations can be found in the appendices.

Figure 9 – van diagram

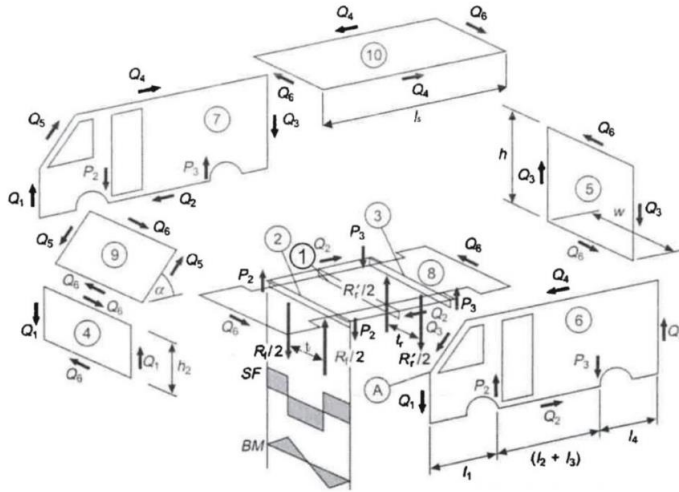


Table 1 – Van data

W	2	m
h	2	m
h ₂	1	m
l ₁	2	m
l ₂ + l ₃	3	m
l ₄	1	m
l ₅	3	m
Weight	3000	kg
Distribution	50-50	
t _f	1.5	m
t _r	1.5	m
alpha	45	°
R _r =R _f	5000	N

Table 2 – Shear loads

Q ₆	535.71	N
Q ₁	267.86	N
Q ₂	1607.14	N
Q ₃	535.71	N
Q ₄	803.57	N
Q ₅	378.81	N

Table 3 - Torsional load

Torsional load applied to vehicle $T=P_2W=P_3W$

P ₂	1875	N
P ₃	1875	N

Total torque applied to vehicle = 3750N

Ordered – largest to smallest

Panel	Shear Load (N/m ²)	MPa
10	133928.57	0.134
9	189403.60	0.189
8	133928.57	0.134
7	141523.68	0.142
6	141523.68	0.142
5	133928.57	0.134
4	267857.14	0.268
1,3	±133928.57	±134

Panel	Shear Load (N/m ²)	MPa
4	267857.14	0.268
9	189403.60	0.189
7	141523.68	0.142
6	141523.68	0.142
10	133928.57	0.134
8	133928.57	0.134
5	133928.57	0.134
1,3	±133928.57	±134

If the back doors in this van (panel 5) were to be removed the this would decimate the structural integrity of the van and cause the shear forces on all subsequent panel forces to be zero which means they are not acting s shear panels, the forces would then disform and bend the overall body structure. The forces prove too much as the panels were not engineered to be under such shear stresses. the back panel is necessary for the success of the other panels. Lack of panel will cause all forces on the vehicle to act on the floor.

Appendices

Task 3 workings

R_f = reaction at front

R_r = reaction at rear

t_f = track at front

t_r = track at rear

$$p = \frac{R_f t_f}{2W}$$

$$p_3 = \frac{R_r t_r}{2W}$$

$$p_2 = \frac{5000(1.5)}{2(2)} = 1875N \quad p_3 = \frac{5000(1.5)}{2(2)} = 1875N$$

$$T = p_2 W = p_3 W \Rightarrow \text{Total} = 3750N$$

$$Q_6 = \frac{W(p_3(L_1 + L_2 + L_3) - p_2 h_1)}{h_1(L_1 + L_2 + L_3 + L_4) + L_5(h_1 - h_2) + h_2(L_1 + L_2 + L_3 + L_4)}$$

$$= \frac{2(1875(5)) - 1875(2)}{2(6) + 3(1) + (6)} = \underline{\underline{535.71N}}$$

$$Q_1 = \frac{Q_6 h_2}{W} \Rightarrow \frac{535.71(1)}{2} = \underline{\underline{267.86N}}$$

$$Q_2 = \frac{Q_6(L_1 + L_2 + L_3 + L_4)}{W} \Rightarrow \frac{535.71(6)}{2} = \underline{\underline{1607.13N}}$$

$$Q_3 = \frac{Q_6 h_1}{W} \Rightarrow \frac{535.71(2)}{2} = \underline{\underline{535.71N}}$$

$$Q_4 = \frac{Q_6 L_5}{W} \Rightarrow \frac{535.71(3)}{2} = \underline{\underline{803.57N}}$$

$$Q_5 = \frac{Q_6(h_1 - h_2)}{W \sin \alpha} \Rightarrow \frac{535.71(1)}{2 \sin 45} = \underline{\underline{377.8N}}$$



$$w = 2$$

$$h_1 = 2$$

$$h_2 = 1$$

$$l_1 = 2$$

$$l_2 + l_3 = 3$$

$$l_4 = 1$$

$$l_5 = 3m$$

$$\alpha_{phk} = 45^\circ$$

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

$$630.47 \times 10^3$$

FFB test

$$F = P_2: \text{Shear} = P_2 = \frac{805.57}{3 \times 2 \times 10^{-3}} = \frac{133.93 \times 10^3}{1,000,000} = 0.134 \text{ MPa}$$

$$P_2 =$$

$$535.71$$

$$P_9 = \frac{535.71}{\sqrt{2} \times 2 \times 10^{-3}} = \frac{189402.08}{1,000,000} = 0.189 \text{ MPa}$$

$$P_8 = \frac{1607.13}{6 \times 2 \times 10^{-3}} = 0.134 \text{ MPa}$$

$$P_7 = \frac{1607.13}{11.356 \times 10^{-3}} = \frac{141572.54 \text{ N/m}^2}{1,000,000} = 0.142 \text{ MPa}$$

$$P_6 = 0.142 \text{ MPa}$$

$$P_5 = \frac{535.71}{2 \times 2 \times 10^{-3}} = \frac{88427.5 \text{ N/m}^2}{1,000,000} = 0.088 \text{ MPa}$$

$$P_4 = \frac{535.71}{2 \times 10^{-3}} = \frac{267.855 \text{ N/m}^2}{1,000,000} = 0.268 \text{ MPa}$$

Formulas

$$P_2 = \frac{R_f t_f}{2w}$$

$$P_3 = \frac{R_r t_r}{2w}$$

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

$$Q_1 = \frac{Q_6 h_2}{w}$$

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

$$Q_3 = \frac{Q_6 h_1}{w}$$

$$Q_4 = \frac{Q_6 l_5}{w}$$

$$Q_5 = \frac{Q_6(h_1 - h_2)}{2 \sin \alpha}$$

$$T = P_2 w = P_3 w$$

$$\tau = \frac{F}{Ax10^{-3}}$$

$$\sigma_{1,3} = \frac{1}{2} \left[(\sigma_x + \sigma_y) \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2} \right]$$

$$\therefore \sigma_{1,3} = \pm \tau_{xy}$$

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