Automobiles Frame Construction

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Frame (vehicle)

A frame is the main structure of an automobile chassis. All other components fasten to it.

1956 Chevrolet 1/2-ton frame. Notice hat-shaped crossmember in the background, c-shape rails and crossmember in center, and a slight arch over the axle.

Construction

There are three main designs for frame rails. These are:

1. C-shaped
2. Boxed
3. Hat

C-shape

By far the most common, the C-rail has been used on nearly every type of vehicle at one time or another. It's made by taking a flat piece of steel (usually ranging in thickness from 1/8" to 3/16") and rolling both sides over to form a c-shaped beam running the length of the vehicle.

Boxed

Originally, boxed frames were made by welding two matching c-rails together to form a rectangular tube. Modern techniques, however, use a process similar to making c-rails in that a piece of steel is bent into four sides and then welded where both ends meet.

Hat

Hat frames resemble a "U" and may be either right-side-up or inverted with the open area facing down. Not commonly used due to weakness and a propensity to rust, however they can be found on 1936-1954 Chevrolet cars and some Studebakers.

Abandoned for a while, the hat frame gained popularity again when companies started welding it to the bottom of unibody cars, in effect creating a boxed frame.

Design Features

While appearing at first glance as a simple hunk of metal, frames encounter great amounts of stress and are built accordingly. The first issue addressed is **beam height**, or the height of the vertical side of a frame. The taller the frame, the better it is able to resist vertical flex when force is applied to the top of the frame. This is the reason semi-trucks have taller frame rails than other vehicles instead of just being thicker.

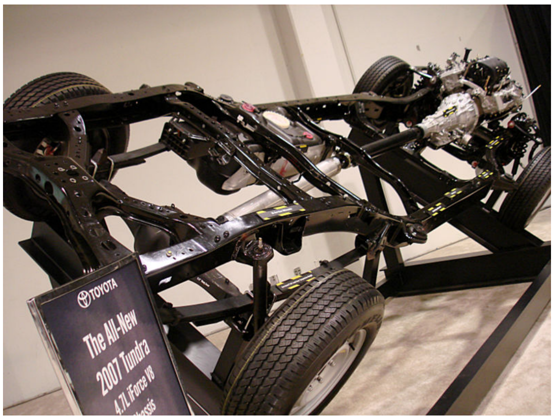
Another factor considered when engineering a frame is torsional resistance, or the ability to resist twisting. This, and diamonding (one rail moving backwards or forwards in relation to the other rail), are countered by crossmembers. While hat-shaped crossmembers are the norm, these forces are best countered with "K" or "X"-shaped crossmembers.

As looks, ride quality, and handling became more of an issue with consumers, new shapes were incorporated into frames. The most obvious of these are arches and kick-ups. Instead of running straight over both axles, arched frames sit roughly level with their axles and curve up over the axles and then back down on the other side for bumper placement. Kick-ups do the same thing, but don't curve down on the other side, and are more common on front ends.

On perimeter frames, the areas where the rails connect from front to center and center to rear are weak compared to regular frames, so that section is boxed in, creating what's known as **torque boxes**.

Another feature seen are tapered rails that narrow vertically and/or horizontally in front of a vehicle's cabin. This is done mainly on trucks to save weight and slightly increase room for the engine since the front of the vehicle doesn't bear as much of a load as the back.

The latest design element is frames that use more than one shape in the same frame rail. For example, the new Toyota Tundra uses a boxed frame in front of the cab, shorter, narrower rails underneath the cab for ride quality, and regular c-rails under the bed.



2007 Toyota Tundra chassis showing an x-shaped crossmember at the back.

Types

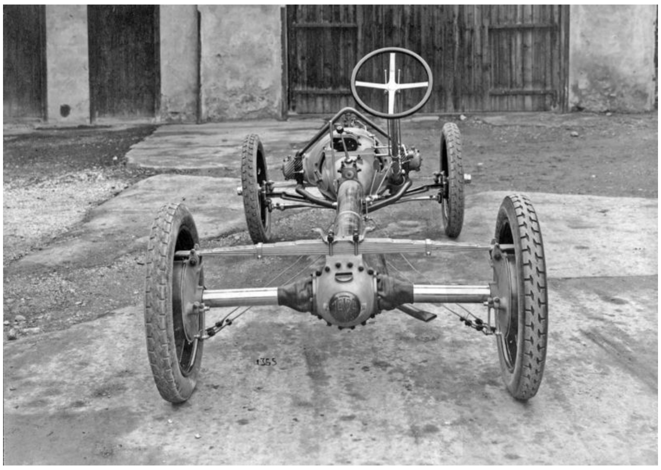
Ladder Frame

So named for its resemblance to a ladder, the ladder frame is the simplest and oldest of all designs. It consists merely of two symmetrical rails, or beams, and crossmembers connecting them. Originally seen on almost all vehicles, the ladder frame was gradually phased out on cars around the 1940s in favor of perimeter frames and is now seen mainly on trucks.

This design offers good beam resistance because of its continuous rails from front to rear, but poor resistance to torsion or warping if simple, perpendicular crossmembers are used. Also, the vehicle's overall height will be higher due to the floor pan sitting above the frame instead of inside it.

Backbone tube

Backbone chassis is a type of an automobile construction chassis that is similar to the body-on-frame design. Instead of a two-dimensional ladder type structure, it consists of a strong tubular backbone (usually rectangular in cross section) that connects the front and rear suspension attachment areas. A body is then placed on this structure.


The backbone tube of Tatra 11

Perimeter Frame

Similar to a ladder frame, but the middle sections of the frame rails sit outboard of the front and rear rails just behind the rocker panels/sill panels. This was done to allow for a lower floor pan, and therefore lower overall vehicle in passenger cars. This was the prevalent design for cars in the United States, but not in the rest of the world, until the uni-body gained popularity and is still used on US full frame cars. It allowed for annual model changes introduced in the 1950s to increase sales, but without costly structural changes.

In addition to a lowered roof, the perimeter frame allows for more comfortable lower seating positions and offers better safety in the event of a side impact. However, the reason this design isn't used on all vehicles is that it lacks stiffness, because the transition areas from front to center and center to rear reduce beam and torsional resistance, hence the use of torque boxes, and soft suspension settings.

Unibody

By far the most common type of frame in use today.

Sub Frame

The sub frame, or stub frame, is a boxed frame section that attaches to a unibody. Seen primarily on the front end of cars, it's also sometimes used in the rear. Both the front and rear are used to attach the suspension to the vehicle and either may contain the engine and transmission.

The most prolific example is the 1967-1981 Chevrolet Camaro.

See also

- Motorcycle frame
- Bicycle frame

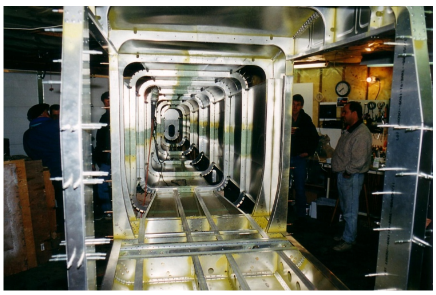
Body Frame Integral

Monocoque is a construction technique that supports structural load by using an object's exterior, as opposed to using an internal frame or truss that is then covered with a non-load-bearing skin or coachwork. The word *monocoque* comes from the Greek for single (*mono*) and French for shell (*coque*). The technique may also be called **structural skin**, **stressed skin**, **unit body**, **unibody**, **unitary construction**, or **Body Frame Integral** (BFI).

Monocoque construction was pioneered in aircraft, with early designs appearing circa 1916, and entering wide use in the 1930s. Automobiles saw monocoque designs as early as 1923, but widespread adoption did not begin until the second half of the 20th century. Today, a welded unit body is the predominant automobile construction technique. Monocoque designs have also been seen in two-wheeled vehicles, water vessels, and architecture.

Aircraft

Early aircraft were constructed using internal frames, typically of wood or steel tubing, which were then covered (or *skinned*) with madapolam or other fabric to provide the aerodynamic surfaces. This fabric would usually be tautened and stiffened using aircraft dope and was often required to brace the frame in tension but could provide no strength in compression; to resist buckling, these aircraft relied on the rigidity of the internal frame. Some early aircraft designers began to apply sheet metal or plywood to highly stressed parts of the internal frames; this skin did provide strength in shear and compression and could therefore be considered as early examples of monocoque elements but the aircraft still relied primarily on their internal frames.



View of the inside of the tail cone of a Murphy Moose homebuilt aircraft under construction, showing the *semi-monocoque* design

Design and development

In 1916 LFG introduced their Roland C.II using a fuselage made of moulded plywood, which provided both the external skin and the main load bearing structure. This made the plane very strong for its day, if a little heavy.

Similar designs were also produced by Pfalz Flugzeugwerke, who had originally built the Roland under license.

By the late 1920s the price of aluminium, the principal ingredient of the aircraft alloy duralumin, had dropped considerably and duralumin was adopted extensively for internal framing members and later, the skin. It was realised that if the skin were made thick enough it could, theoretically, eliminate the need for any internal framing at all but this would be heavier than an internal frame. Thin sheet metal gauges could easily resist tension and shear loads but buckled under bending and compression. However, if curved, corrugated or rolled into pipe, sheet metal could be made strong against bending and compression loads as well. Stressed skins began to be combined with greatly reduced internal stiffening and came to be what is now known as *semi-monocoque*.

For example, the Ford Trimotor retained an internal frame of U-shaped aluminium beams but relied on a thin skin of corrugated aluminium sheet to brace this. The corrugations allowed the Trimotor skin to take compression and bending loads, replacing most of the wing ribs and fuselage stringers and could be regarded as a stressed skin structure augmented by an internal frame or semi-monocoque structure. The skin itself had now become a significant structural element in its own right and it was to become even more important when airframes were required to take ever increasing loads.

In the 1930s huge increases in engine power, higher speeds, the need for fuel efficiency and, post World War II, operating altitudes that required aircraft cabins to be pressurised demanded streamlined airframes with stiff, strong, smooth skins; monocoque construction was ideal for this. Torsional (twisting) stiffness was essential to avoid aerolastic deformation under the rising aerodynamic loads. An outstanding early example is the Douglas DC-3. World War II was a major catalyst for aircraft development. At the beginning of the war monocoque construction was in its infancy and many aircraft still used mixed construction or internal frames; by the end of the war, all high-performance planes were monocoque or semi-monocoque.

Aerodynamic considerations of high performance aircraft began to demand the creation of three-dimensionally curved surfaces; a dome is a three-dimensionally curved surface. Happily, any sheet material acquires far more strength when curved in three dimensions as opposed to a simple two dimensional roll such as the Tri-motors corrugated skin. Although expensive to mould, three dimensional shells such as the de Havilland Mosquito moulded plywood fuselage provided immensely strong and light airframes. De Havilland built thousands of wooden monocoque jet aircraft, the Vampires, copying their very successful Mosquito structure.

Limitations

Monocoque construction does not suit all situations. After World War II many lower-performance general aviation aircraft such as the Piper PA-20 Pacer still employed internal frames. Even external wire bracing is still retained for aircraft that have no internal volume such as hang gliders or ultralight, lightly stressed, slow aircraft for which a stressed skin would be too heavy, such as the human powered Gossamer Condor. This is because for very light loads skin stiffness becomes less important than airframe buckling and buckling can be resisted more weight-efficiently by concentrating the compression loads into a few internal struts kept in place by lightweight wire or fabric tension members. Bicycle wheels and tents use tension members in the same way to brace a few compression parts. Monocoque construction can still be more efficient, even in lightly loaded situations, where torsional resistance is the primary need.

An inadequate understanding of early, metal monocoque aircraft design resulted in catastrophic explosive decompressions of pressurised airframes. The two 1954 De Havilland Comet disasters resulted in a major investigation that solved the principal problems of monocoque aircraft construction. It was found that the Comet fuselage failures were caused by a combination of a poor understanding of how stresses are redistributed around openings in a stressed skin, stress raisers such as windows with corners, and an inadequate theory of metal fatigue crack propagation on a pressurised fuselage, that cycles between a pressurised and unpressurised state on every flight. The lessons learnt by the British Royal Aircraft Establishment investigation from the early Comet flaws, were incorporated directly into the design of the Boeing 707 and all subsequent airliners. The oval windows seen on all pressurised jet airliners are one legacy of this. Sound engineering and regular inspections for metal fatigue have made aircraft airframes very reliable. When a crack is found, all parts from that batch are traced and checked carefully or replaced.

Modern technologies

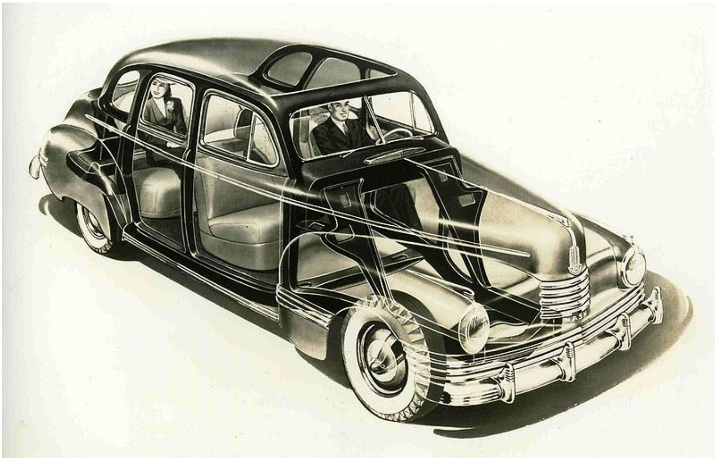
The use of composite materials in monocoque skins now allows strength, stiffness and flexibility to be controlled in different directions. Careful design of the direction of the grain of successive layers of materials used in the skin coupled with the use of carbon fibre or other non isotropic composites can produce different mechanical properties in different directions while optimising for weight. Composite materials can be readily built up into complex three-dimensional shapes making them ideal for many aircraft components. They can also be built to be flexible in useful ways, for example, helicopter blades can be made longitudinally rigid but capable of being twisted transversally to adjust the cyclic pitch instead of being mounted on a pivot.

First-stage view of the Falcon I rocket

Various rockets also use a flight pressure-stabilized monocoque design, including the Atlas II and Falcon I.

Automobiles

Similar to aircraft, automobile designs originally used body-on-frame construction, where a load-bearing chassis consisting of frame, powertrain, and suspension formed the base vehicle, and supported a non-load-bearing body or coachwork. Over time, this was supplanted by monocoque designs, integrating the body and chassis into a single unit. The external panels may be *stressed*, in such cases as the rocker panels, windshield frame and roof pillars, or *non-stressed*, as is often the case with fenders. Today, spot welded unit body is the dominant technique, although some vehicles (particularly trucks and buses) still use body-on-frame.


Cutaway drawing of the 1942 Nash 600 body design

Early designs

The first automotive application of the monocoque technique was 1923's Lancia Lambda, but it was not a true monocoque because it did not have a stressed roof, it was akin to a boat and has been described as 'punt' type construction. In 1928 German motorcycle manufacturer DKW launched their first car, the P15 wood and fabric bodied monocoque car. The Airflow and Traction Avant steel partially monocoque cars (stressed panels on internal frames) were both launched in 1934. General Motors then followed with the Opel Olympia in 1935. In 1936, Lincoln introduced the Zephyr, a monocoque design which was as strong as the Airflow yet much lighter.

A halfway house to full monocoque construction was the 'semi-monocoque' used by the 1930s designed Volkswagen Beetle. This used a lightweight separate chassis made from pressed sheet steel panels forming a 'platform chassis', to give the benefits of a traditional chassis, but with lower weight and greater stiffness. This chassis was used for several different models. Volkswagen made use of the bodyshell for structural strength as well as the chassis - hence 'semi-monocoque'.

Nash Motors introduced this type of construction in 1941 with the new 600, generally credited with being the first popular mass-produced unibody construction automobile made in the United States. The all-welded steel with sturdy bridge-like girders that arched front to rear made for improved strength, safety, and durability. Nash engineers claimed that about 500 pounds of excess weight was cut out (compared to body-on-frame automobiles) and the body's lower air drag helped it to achieve better gas mileage. The company's 1942 news release text attached to the X-ray drawing describes how "*... all auto bodies will be built ... as this some day...*"

Post-war advancements

After World War II, the technique became more widely used. The Alec Issigonis Morris Minor of 1948 featured a monocoque body, as did the Hudson Motor range of the same time. The Australian Holden of 1948 was monocoque-bodied and built by General Motors-Holden in Australia. Other automakers incorporated this type of construction, and the terms *unit body* and *unibody* became more common in general use. The Ford Consul was the first Ford built in England using a unibody.

In 1960, a major breakthrough in unibody construction was reached in mass-produced Detroit vehicles with over 99% of Chrysler vehicles produced that year being fully unitized; some of the basic designs surviving almost untouched through the mid 1970s (EG: Valiant, Dart, etc.) with tens of millions eventually produced. Convertible versions needed special supports welded underneath to compensate for the missing shape on the top.

American Motors (AMC) continued its engineering heritage from Nash and Hudson, in 1963 combining separate parts into single stampings. The Rambler Classic had "uniside" door surrounds from a single stamping of steel that reduced weight and assembly costs, as well as increasing structural rigidity and improving door fitment.

Hybrid designs

Some American automobiles, such as the 1967-81 Chevrolet Camaro and Pontiac Firebird, 1968-79 Chevrolet Nova and many larger Chrysler Corporation RWD automobiles from 1965 until 1989, used a compromise design with a partial monocoque combined with a rubber-isolated subframe carrying the front end and powertrain. The intention was to provide some of the rigidity and strength of a unibody while easing manufacture. Results were mixed, in large part because the powertrain subframe contained the greatest single portion of the vehicle's overall mass, and thus movement of the subframe relative to the rest of the body could cause distortion and vibration. Subframes or partial subframes are still sometimes employed in otherwise monocoque construction, typically as a way of isolating the vibration and noise of powertrain or suspension components from the rest of the vehicle.

Modern monocoques

In automobiles, it is now common to see true monocoque frames, where the structural members around the window and door frames are built by folding the skin material several times. In these situations the main concerns are spreading the load evenly, having no holes for corrosion to start, and reducing the overall workload. Compared to older techniques, in which a body is bolted to a frame, monocoque cars are less expensive, lighter, more rigid, and can be more protective of occupants in a crash when appropriately designed. The use of higher strength steels in panels at points of high stress has increased strength and rigidity without increasing weight.

In sophisticated monocoque designs, the windshield and rear window glass is bonded in place and often makes an important contribution to the designed structural strength of automobiles.

Some parts of the skin like the grill, the bumpers, the fenders, front wing and rear diffuser are so far away from any load paths that they only hold themselves. The doors and the hood can only transfer a limited amount of load across their gaskets, hinges, and bolts in normal driving situations. The rear door is both far away from any load paths and separated by a gasket. The rear door is a mini-monocoque made of the glass window and the metal frame.

Monocoque designs are favored amongst high-performance cars and racing cars today for their overall structural integrity and the fact that one can design a monocoque out of lightweight materials such as carbon fiber and expect the resulting vehicle to be light, stiff, and stable at high speeds and in tight corners. These types of particularly advanced monocoques can even be molded to create diffusers and ground effects which generate huge amounts of downforce.

Disadvantages

Unfortunately, when a vehicle with a unibody design is involved in a serious accident, it may be more difficult to repair than a vehicle with a full frame. Rust can be more of a problem, since the structural metal is part of the load bearing structure (of metal that is much thinner than a conventional chassis) making it more critical, and must be repaired by cutting-out and welding rather than by simply bolting on new parts (as would be the case for a separate chassis). Structural rust of monocoque cars was a serious problem until the 1990s. Since then, more and more car makers have adopted protection techniques such as galvanizing for structural areas or for the whole body.

Older cars with separate chassis can still pass vehicle inspection tests (such as the British MoT) with quite advanced rust in the sills (rocker panels) and pillars, whereas in more modern cars these parts are structural and would lead to a test failure. In the United States, in the majority of the states which require safety inspections, vehicles will not pass inspection if rust has perforated components such as rocker panels, floor pans, or pillars - regardless of the type of body construction.

Armored vehicles

Tanks and other armored vehicles generally use a body or chassis which is built of the armor rather than attaching armor to a body-on-frame design. Though this generally produces a fairly heavy vehicle, it can reduce weight for a given amount of armor compared to soft-skinned vehicles to which armor has been added either as a modification or a kit. For example, the German Fuchs 2 [1] and RG-33 have monocoque hulls rather than a separate body and frame, while the truck-based M3 Half-track and up-armored humvee have separate bodies to which armor has been added.

Two-wheeled vehicles

LCR Sidecar in race paddock

Traditional bicycles are not monocoques; they are classic framed structures. However, carbon fibre monocoque framesets are slowly emerging in high-end competitive bicycles, due to their stiffness and light weight. The American company Kestrel USA pioneered [2] the use of carbon fibre monocoques in bike frame manufacture in the 1980s, and since then the technique has become increasingly widely used. Items such as seat-posts and other components are now employing the same technique.

A Grand Prix motorcycle racing monocoque motorcycle was developed in 1967 by Ossa, a Spanish motorcycle brand. Notable designers such as Eric Offenstadt [3] and Dan Hanebrink [4] created unique monocoque designs in the early 1970's. The 1973 Isle of Man TT was won by Peter Williams on the monocoque-framed Norton John Player Special. Honda also experimented with a monocoque motorcycle in 1979 with its NR500 [5] . In 1987 John Britten developed the Aero-D One featuring a composite monocoque chassis that only weighed 12kg.[6] In 2009 Ducati introduced the Desmosedici GP9 with a carbon fibre semi-monocoque chassis.

Road racing sidecars in the Formula 1 class have used monocoque chassis since the mid 1970s, such as those manufactured by LCR.

Motor scooters are often made from a pressed steel monocoque frame. This design leads to a light weight and high fuel efficiency, contributing to their popularity.


Aluminum monocoque downhill mountainbike frame.

Water vessels

Frameless glass fibre reinforced or moulded plastic kayaks and canoes and reinforced concrete yacht hulls are monocoques, larger ships tend to have frames but may be hybrids with stressed skins over frames. A submarine has a massive tubular pressure hull at its heart designed primarily to withstand water pressure but because this is so strong it essentially forms a massive stressed skin and can be regarded as a monocoque.

Architecture

Architects occasionally take advantage of the increasing sophistication of monocoque technology in their building projects. Using monocoque technology in buildings allows for interior spaces without columns and load-bearing walls; this creates more spatial and programmatic openness inside. Notable examples are reinforced concrete shells.

Many 1950s and 1960s UK underground protected nuclear bunkers were constructed as reinforced concrete monocoque structures for their inherent strength, robustness and protective factors. Often described as "underground submarines" in that, if they were dug up and placed in water, they would have floated and stayed waterproof.

Media Centre at Lord's Cricket Ground is a semi-monocoque aluminium structure designed by London based Future Systems in 1999 and built by Pendennis Shipyard in Falmouth drawing on the company's boatbuilding experience.

The *Wichita House* designed by Buckminster Fuller used monocoque construction based on the Dymaxion design.[7]

Architect Neil Denari incorporates a monocoque-like approach to the cladding and external appearances of otherwise conventionally-structured projects.

A geodesic dome is a hybrid design, combining monocoque and frame elements as are Quonset huts.

Structural Insulated Panels, or SIPs, are a type of preinsulated modular wall system. Formerly called "stressed skin panels", they are monocoques in and of themselves. Fastened together properly, they can yield a monocoque housing structure.

See also

- Backbone chassis
- Frame (vehicle)
- Chassis
- Coachwork
- Body-on-frame
- Coachbuilder
- Strut bar
- Airframe
- Spaceframe
- Superleggera
- Thin-shell structure

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Coachwork

Coachwork is the body of a motor vehicle (automobile, bus or truck) which is built around a chassis, rather than being of monocoque construction. Another word is *carrossery* (plural: *carosseries*).

See also

- Body-on-frame
- Car body style
- List of auto parts
- Automobile repair shop
- Bus manufacturing
- Coachbuilder
- Monocoque

Monocoque

Monocoque is a construction technique that supports structural load by using an object's exterior, as opposed to using an internal frame or truss that is then covered with a non-load-bearing skin or coachwork. The word *monocoque* comes from the Greek for single (*mono*) and French for shell (*coque*). The technique may also be called **structural skin**, **stressed skin**, **unit body**, **unibody**, **unitary construction**, or **Body Frame Integral** (BFI).

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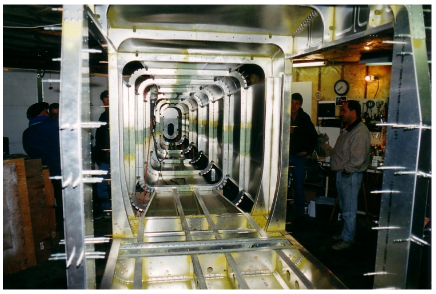

View of the inside of the tail cone of a Murphy Moose homebuilt aircraft under construction, showing the *semi-monocoque* design

Design and development

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Aerodynamic considerations of high performance aircraft began to demand the creation of three-dimensionally curved surfaces; a dome is a three-dimensionally curved surface. Happily, any sheet material acquires far more strength when curved in three dimensions as opposed to a simple two dimensional roll such as the Tri-motors corrugated skin. Although expensive to mould, three dimensional shells such as the de Havilland Mosquito moulded plywood fuselage provided immensely strong and light airframes. De Havilland built thousands of wooden monocoque jet aircraft, the Vampires, copying their very successful Mosquito structure.

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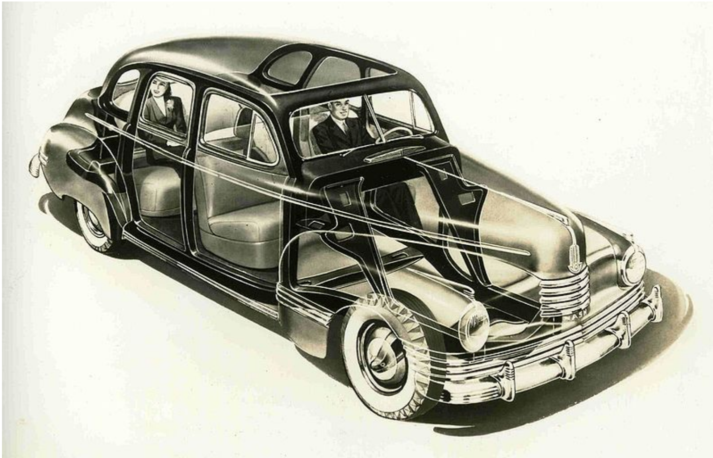
Modern technologies

First-stage view of the Falcon I rocket

The use of composite materials in monocoque skins now allows strength, stiffness and flexibility to be controlled in different directions. Careful design of the direction of the grain of successive layers of materials used in the skin coupled with the use of carbon fibre or other non isotropic composites can produce different mechanical properties in different directions while optimising for weight. Composite materials can be readily built up into complex three-dimensional shapes making them ideal for many aircraft components. They can also be built to be flexible in useful ways, for example, helicopter blades can be made longitudinally rigid but capable of being twisted transversally to adjust the cyclic pitch instead of being mounted on a pivot.

Various rockets also use a flight pressure-stabilized monocoque design, including the Atlas II and Falcon I.

Automobiles



Cutaway drawing of the 1942 Nash 600 body design

Similar to aircraft, automobile designs originally used body-on-frame construction, where a load-bearing chassis consisting of frame, powertrain, and suspension formed the base vehicle, and supported a non-load-bearing body or coachwork. Over time, this was supplanted by monocoque designs, integrating the body and chassis into a single unit. The external panels may be *stressed*, in such cases as the rocker panels, windshield frame and roof pillars, or *non-stressed*, as is often the case with fenders. Today, spot welded unit body is the dominant technique, although some vehicles (particularly trucks and buses) still use body-on-frame.

Early designs

The first automotive application of the monocoque technique was 1923's Lancia Lambda, but it was not a true monocoque because it did not have a stressed roof, it was akin to a boat and has been described as 'punt' type construction. In 1928 German motorcycle manufacturer DKW launched their first car, the P15 wood and fabric bodied monocoque car. The Airflow and Traction Avant steel partially monocoque cars (stressed panels on internal frames) were both launched in 1934. General Motors then followed with the Opel Olympia in 1935. In 1936, Lincoln introduced the Zephyr, a monocoque design which was as strong as the Airflow yet much lighter.

A halfway house to full monocoque construction was the 'semi-monocoque' used by the 1930s designed Volkswagen Beetle. This used a lightweight separate chassis made from pressed sheet steel panels forming a 'platform chassis', to give the benefits of a traditional chassis, but with lower weight and greater stiffness. This chassis was used for several different models. Volkswagen made use of the bodyshell for structural strength as well as the chassis - hence 'semi-monocoque'.

Nash Motors introduced this type of construction in 1941 with the new 600, generally credited with being the first popular mass-produced unibody construction automobile made in the United States. The all-welded steel with sturdy bridge-like girders that arched front to rear made for improved strength, safety, and durability. Nash engineers claimed that about 500 pounds of excess weight was cut out (compared to body-on-frame automobiles) and the body's lower air drag helped it to achieve better gas mileage. The company's 1942 news release text attached to the X-ray drawing describes how "*... all auto bodies will be built ... as this some day...*"

Post-war advancements

After World War II, the technique became more widely used. The Alec Issigonis Morris Minor of 1948 featured a monocoque body, as did the Hudson Motor range of the same time. The Australian Holden of 1948 was monocoque-bodied and built by General Motors-Holden in Australia. Other automakers incorporated this type of construction, and the terms *unit body* and *unibody* became more common in general use. The Ford Consul was the first Ford built in England using a unibody.

In 1960, a major breakthrough in unibody construction was reached in mass-produced Detroit vehicles with over 99% of Chrysler vehicles produced that year being fully unitized; some of the basic designs surviving almost untouched through the mid 1970s (EG: Valiant, Dart, etc.) with tens of millions eventually produced. Convertible versions needed special supports welded underneath to compensate for the missing shape on the top.

American Motors (AMC) continued its engineering heritage from Nash and Hudson, in 1963 combining separate parts into single stampings. The Rambler Classic had "uniside" door surrounds from a single stamping of steel that reduced weight and assembly costs, as well as increasing structural rigidity and improving door fitment.

Hybrid designs

Some American automobiles, such as the 1967-81 Chevrolet Camaro and Pontiac Firebird, 1968-79 Chevrolet Nova and many larger Chrysler Corporation RWD automobiles from 1965 until 1989, used a compromise design with a partial monocoque combined with a rubber-isolated subframe carrying the front end and powertrain. The intention was to provide some of the rigidity and strength of a unibody while easing manufacture. Results were mixed, in large part because the powertrain subframe contained the greatest single portion of the vehicle's overall mass, and thus movement of the subframe relative to the rest of the body could cause distortion and vibration. Subframes or partial subframes are still sometimes employed in otherwise monocoque construction, typically as a way of isolating the vibration and noise of powertrain or suspension components from the rest of the vehicle.

Modern monocoques

In automobiles, it is now common to see true monocoque frames, where the structural members around the window and door frames are built by folding the skin material several times. In these situations the main concerns are spreading the load evenly, having no holes for corrosion to start, and reducing the overall workload. Compared to older techniques, in which a body is bolted to a frame, monocoque cars are less expensive, lighter, more rigid, and can be more protective of occupants in a crash when appropriately designed. The use of higher strength steels in panels at points of high stress has increased strength and rigidity without increasing weight.

In sophisticated monocoque designs, the windshield and rear window glass is bonded in place and often makes an important contribution to the designed structural strength of automobiles.

Some parts of the skin like the grill, the bumpers, the fenders, front wing and rear diffuser are so far away from any load paths that they only hold themselves. The doors and the hood can only transfer a limited amount of load across their gaskets, hinges, and bolts in normal driving situations. The rear door is both far away from any load paths and separated by a gasket. The rear door is a mini-monocoque made of the glass window and the metal frame.

Monocoque designs are favored amongst high-performance cars and racing cars today for their overall structural integrity and the fact that one can design a monocoque out of lightweight materials such as carbon fiber and expect the resulting vehicle to be light, stiff, and stable at high speeds and in tight corners. These types of particularly advanced monocoques can even be molded to create diffusers and ground effects which generate huge amounts of downforce.

Disadvantages

Unfortunately, when a vehicle with a unibody design is involved in a serious accident, it may be more difficult to repair than a vehicle with a full frame. Rust can be more of a problem, since the structural metal is part of the load bearing structure (of metal that is much thinner than a conventional chassis) making it more critical, and must be repaired by cutting-out and welding rather than by simply bolting on new parts (as would be the case for a separate chassis). Structural rust of monocoque cars was a serious problem until the 1990s. Since then, more and more car makers have adopted protection techniques such as galvanizing for structural areas or for the whole body.

Older cars with separate chassis can still pass vehicle inspection tests (such as the British MoT) with quite advanced rust in the sills (rocker panels) and pillars, whereas in more modern cars these parts are structural and would lead to a test failure. In the United States, in the majority of the states which require safety inspections, vehicles will not pass inspection if rust has perforated components such as rocker panels, floor pans, or pillars - regardless of the type of body construction.

Armored vehicles

Tanks and other armored vehicles generally use a body or chassis which is built of the armor rather than attaching armor to a body-on-frame design. Though this generally produces a fairly heavy vehicle, it can reduce weight for a given amount of armor compared to soft-skinned vehicles to which armor has been added either as a modification or a kit. For example, the German Fuchs 2 [1] and RG-33 have monocoque hulls rather than a separate body and frame, while the truck-based M3 Half-track and up-armored humvee have separate bodies to which armor has been added.

Two-wheeled vehicles

Traditional bicycles are not monocoques; they are classic framed structures. However, carbon fibre monocoque framesets are slowly emerging in high-end competitive bicycles, due to their stiffness and light weight. The American company Kestrel USA pioneered [2] the use of carbon fibre monocoques in bike frame manufacture in the 1980s, and since then the technique has become increasingly widely used. Items such as seat-posts and other components are now employing the same technique.

LCR Sidecar in race paddock

A Grand Prix motorcycle racing monocoque motorcycle was developed in 1967 by Ossa, a Spanish motorcycle brand. Notable designers such as Eric Offenstadt [3] and Dan Hanebrink [4] created unique monocoque designs in the early 1970's. The 1973 Isle of Man TT was won by Peter Williams on the monocoque-framed Norton John Player Special. Honda also experimented with a monocoque motorcycle in 1979 with its NR500 [5] . In 1987 John Britten developed the Aero-D One featuring a composite monocoque chassis that only weighed 12kg.[6] In 2009 Ducati introduced the Desmosedici GP9 with a carbon fibre semi-monocoque chassis.

Aluminum monocoque downhill mountainbike frame.

Road racing sidecars in the Formula 1 class have used monocoque chassis since the mid 1970s, such as those manufactured by LCR.

Motor scooters are often made from a pressed steel monocoque frame. This design leads to a light weight and high fuel efficiency, contributing to their popularity.

Water vessels

Frameless glass fibre reinforced or moulded plastic kayaks and canoes and reinforced concrete yacht hulls are monocoques, larger ships tend to have frames but may be hybrids with stressed skins over frames. A submarine has a massive tubular pressure hull at its heart designed primarily to withstand water pressure but because this is so strong it essentially forms a massive stressed skin and can be regarded as a monocoque.

Architecture

Architects occasionally take advantage of the increasing sophistication of monocoque technology in their building projects. Using monocoque technology in buildings allows for interior spaces without columns and load-bearing walls; this creates more spatial and programmatic openness inside. Notable examples are reinforced concrete shells.

Many 1950s and 1960s UK underground protected nuclear bunkers were constructed as reinforced concrete monocoque structures for their inherent strength, robustness and protective factors. Often described as "underground submarines" in that, if they were dug up and placed in water, they would have floated and stayed waterproof.

Media Centre at Lord's Cricket Ground is a semi-monocoque aluminium structure designed by London based Future Systems in 1999 and built by Pendennis Shipyard in Falmouth drawing on the company's boatbuilding experience.

The *Wichita House* designed by Buckminster Fuller used monocoque construction based on the Dymaxion design.[7]

Architect Neil Denari incorporates a monocoque-like approach to the cladding and external appearances of otherwise conventionally-structured projects.

A geodesic dome is a hybrid design, combining monocoque and frame elements as are Quonset huts.

Structural Insulated Panels, or SIPs, are a type of preinsulated modular wall system. Formerly called "stressed skin panels", they are monocoques in and of themselves. Fastened together properly, they can yield a monocoque housing structure.

See also

- Backbone chassis
- Frame (vehicle)
- Chassis
- Coachwork
- Body-on-frame
- Coachbuilder
- Strut bar
- Airframe
- Spaceframe
- Superleggera
- Thin-shell structure

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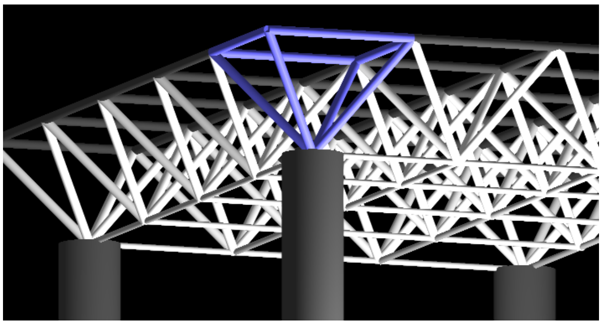
Space frame

A **space frame** or **space structure** is a truss-like, lightweight rigid structure constructed from interlocking struts in a geometric pattern. Space frames usually utilize a multidirectional span, and are often used to accomplish long spans with few supports. They derive their strength from the inherent rigidity of the triangular frame; flexing loads (bending moments) are transmitted as tension and compression loads along the length of each strut.



Simplified space frame roof with the half-octahedron highlighted in blue

Most often their geometry is based on platonic solids. The simplest form is a horizontal slab of interlocking square pyramids built from aluminium or tubular steel struts. In many ways this looks like the horizontal jib of a tower crane repeated many times to make it wider. A stronger purer form is composed of interlocking tetrahedral pyramids in which all the struts have unit length. More technically this is referred to as an isotropic vector matrix or in a single unit width an octet truss. More complex variations change the lengths of the struts to curve the overall structure or may incorporate other geometrical shapes.

Space frames were independently developed by Alexander Graham Bell around 1900 and Buckminster Fuller in the 1950s. Bell's interest was primarily in using them to make rigid frames for nautical and aeronautical engineering although few if any were realised. Buckminster Fuller's focus was architectural structures and has had more lasting influence.

Space frames are an increasingly common architectural technique especially for large roof spans in modernist commercial and industrial buildings.

Notable examples of buildings based on space frames are:

- Stansted airport in London, by Foster and Partners
- I. M. Pei's Bank of China Tower and the Louvre Pyramid
- Rogers Centre by Rod Robbie and Michael Allan
- McCormick Place East in Chicago
- Eden Project in Cornwall, England
- Globen, Sweden - Dome with diameter of 110 m, (1989)
- Biosphere 2 in Oracle, Arizona
- Big Hangar for Iberia Desarrollo Barcelona in Barcelona's airport [1]

Larger portable stages and lighting gantries are also frequently built from space frames and octet trusses.

Tubular space frames are also widely used in the production of modern motorcycles and automobiles, but monocoque car bodies have been more common since the 1950s. Most purpose built race cars used in sports car and stock car racing use tube frame chassis. In automotive context spaceframe construction refers to a design where body panel and other subsystems are assembled onto a structural frame. This differs from a body-on-frame design in that the parts and smaller subassemblies are attached to the frame rather than assembled into a body unit which is then attached to a frame. Spaceframes have also been used in the latest incarnations of the unorthodox bicycles designed by Alex Moulton. The first automotive aluminum space frame appeared on the Honda NSX, other examples include the Audi A8, Caterham 7, Ferrari 360, Lamborghini Gallardo, and Mercedes-Benz SLS AMG.

In February 1986, Paul C. Kranz walked into the U. S. Department of Transportation office in Fort Worth, Texas, with a model of an octet truss. He showed a staff person there how the octet truss was ideal for holding signs over roads. The idea and model was forwarded to HQ USDT in Washington, D. C. Today, the octet truss is the structure of choice for holding signs above roads in the United States.

See also

- Platonic solids
- Body-on-frame
- Monocoque
- Backbone chassis
- Tensegrity

External links

Academic Links

- University of Surrey - Space Structures Research [2]

Informational Links

- Uskon Space Frames [3]
- www.archistructures.org [4]
- www.buschindustries.com [5]
- www.deltastructurescom [6]
- www.MERO.de [7]
- www.MERO-Structures.com [8]
- www.novumstructures.com [9]
- octet truss 3D animation [10]
- **(English)**Aluminum alloy spaceframe [11]
- **(Italian)**Strutture Reticolari in Alluminio [12]
- USTEM www.ustem.com.tr [13]
- Asteca Estructuras [14]
- **(Chinese (Taiwan))**principle [15]

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[3] http://www.uskon.com/eng/
[4] http://www.archistructures.org/
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Subframe

A **subframe** is a structural component of a vehicle, such as an automobile or an aircraft, that uses a discrete, separate structure within a larger body-on-frame or unit body to carry certain components, such as the engine, drivetrain, or suspension. The subframe is bolted and/or welded to the vehicle. When bolted, it is sometimes equipped with rubber bushings or springs to dampen vibration.

The principal purposes of using a subframe are, to spread high chassis loads over a wide area of relatively thin sheet metal of a monocoque body shell, and to isolate vibration and harshness from the rest of the body. For example, in an automobile with its powertrain contained in a subframe, forces generated by the engine and transmission can be damped enough that they will not disturb passengers. As a natural development from a car with a full chassis, separate front and rear subframes are used in modern vehicles to reduce the overall weight and cost. In addition a subframe yields benefits to production in that subassemblies can be made which can be introduced to the main bodyshell when required on an automated line.

There are generally three basic forms of the subframe.

1. A simple "axle" type which usually carries the lower control arms and steering rack.
2. A perimeter frame which carries the above components but in addition supports the engine.
3. A perimeter frame which carries the above components but in addition supports the engine, transmission and possibly full suspension. (As used on front wheel drive cars)

A subframe is usually made of pressed steel panels that are much thicker than bodyshell panels, which are welded or spot welded together. The use of Hydroformed tubes may also be used.

The revolutionary monocoque transverse engined front wheel drive 1959 Austin Mini, that set the template for modern front wheel drive cars, used front and rear subframes to provide accurate road wheel control while using a stiff lightweight body. The 1961 Jaguar E-type or XKE used a tubular spaceframe type front subframe to mount the engine gearbox and long bonnet / hood, to a monocoque 'tub' passenger compartment. The sub frame saw regular production in the 60's and 70's General Motors X and F cars.

Superleggera

Touring Superleggera emblem in a Lamborghini car

Superleggera is an automobile construction technology used in Italy from the middle of the 20th century. The name means "super light" in Italian, and was coined in 1937 by the Italian coachbuilder, Carrozzeria Touring. Unlike the monocoque and body-on-frame methods widely adopted by the 1950s, Superleggera cars use a frame of metal tubes as a full-body frame which closely follow the shape of the car. These are then covered with body panels, made of aluminium. The Superleggera frame tubes are too small and of unsuitable material for mounting suspension components. This distinguishes it very clearly from spaceframe construction where no separate chassis is required.

The Superleggera construction method was primarily based on the use of 'Duraluminium', which originated from the aeronautic industry just before World War II. Carrozzeria Touring sold a Superleggera license to Aston Martin, who used it for their DB4, 5 and 6 models.This construction technique is no longer used in volume production cars today.

In 2008, a new Superleggera chassis was introduced by the Carrozzeria Touring Superleggera srl. of Milan for their new A8GCS Berlinetta prototype with Maserati mechanical parts.

Notable superleggera models include:

- Alfa Romeo 8C 2900 Mille Miglia
- Aston Martin DB4 and DB5
- Pegaso Z-102
- Ferraris 166, 195, 212 and 340 models
- Lamborghini 350GTV
- Lancia Flaminia Convertible
- BMW 328 Touring Roadster

See also

- Monocoque
- Body-on-frame
- Spaceframe
- Backbone chassis

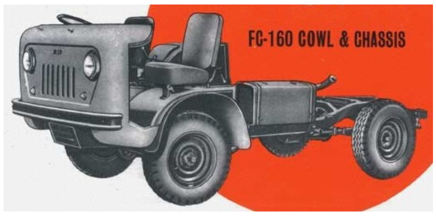
Chassis

A **chassis** (plural: "chassis") (pronounced /ˈʃæsi, ˈtʃæsi/) consists of an internal framework that supports a man-made object. It is analogous to an animal's skeleton. An example of a chassis is the under part of a motor vehicle, consisting of the frame (on which the body is mounted) with the wheels and machinery.

Motor vehicle chassis with its suspension, exhaust system, and steering box

Examples of use

In the case of vehicles, the term chassis means the frame plus the "running gear" like engine, transmission, driveshaft, differential, and suspension. A body (sometimes referred to as "coachwork"), which is usually not necessary for integrity of the structure, is built on the chassis to complete the vehicle. Commercial vehicle manufacturers may have “chassis only”, “cowl and chassis”, as well as "cab and chassis" versions that can be outfitted with specialized bodies. These include motor homes, fire engines, ambulances, box trucks, etc.



1950s Jeep FC cowl and chassis for others to convert into finished vehicles.

- A armoured fighting vehicle's chassis (hull) comprises the bottom part of the AFV, which includes the tracks, engine, driver's seat, and crew compartment. This describes the lower hull, although common usage of might include the upper hull to mean the AFV without the turret. Chassis often serve as basis for platforms on tanks, armored personnel carriers, combat engineering vehicles, etc.
- A chassis in a television, radio, or other electronic device consists of the metal frame on which the circuit boards and other electronics are mounted. In the absence of a metal frame the chassis refers to the circuit boards and components themselves, not the physical structure.
- In computers, the chassis refers to the rigid framework onto which the motherboard, memory, disk drives, and other equipment are mounted. It also supports the shell-like *case*: the housing that protects all of the vital internal equipment from dust, moisture, and tampering. The term "case modding" refers to the artistic styling of otherwise rather functional and plain computer encasings. Main article: computer case for personal machines or rack mount for commercial grade servers.

See also

- Frame (vehicle)
- Backbone chassis
- Body-on-frame
- Monocoque, structural shell, instead of a structural frame
- Tank chassis
- 19-inch rack

Backbone chassis

Tatra T138 backbone tube chassis

Backbone tube chassis is a type of an automobile construction chassis that is similar to the body-on-frame design. Instead of a two-dimensional ladder type structure, it consists of a strong tubular backbone (usually rectangular in cross section) that connects the front and rear suspension attachment areas. A body is then placed on this structure.

It is almost a trademark design feature of Czech Tatra heavy trucks[1] (cross-country, military etc.) - Hans Ledwinka developed this style of chassis for Tatra in 1923[2] with the model Tatra 11. He further enhanced the design with 6x4 model Tatra 26 which had excellent offroad abilities.

This type of chassis is also often found on some sports cars. It also does not provide protection against side collisions, and has to be combined with a body that would compensate for this shortcoming.

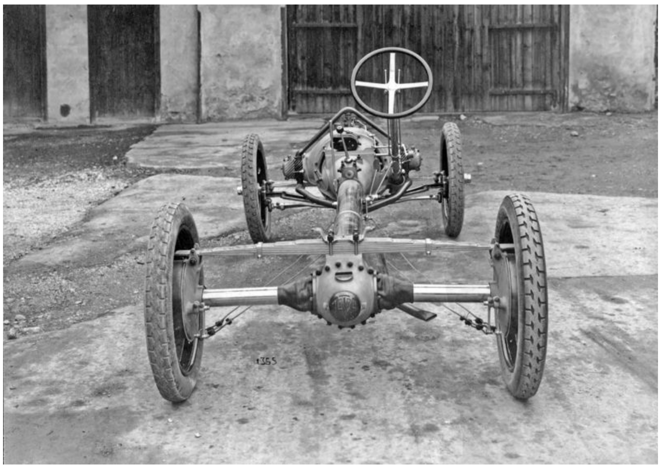
Examples of cars using a backbone chassis include DeLorean DMC-12, Lloyd 600, Lotus Elan, Lotus Esprit and Europa, Škoda 420 Popular, Tatra T-87, Tatra T111, Tatra T148, Tatra T815 etc., as well as TVR S1. Some cars also use a backbone as a part of the chassis to strengthen it; examples include the Volkswagen Beetle and the Locost where the transmission tunnel forms a backbone.

Advantages

- Standard conception truck's superstructure has to withstand the torsion twist and subsequent tear and wear reduces vehicle's lifespan.
- The half-axles have better contact with ground when operated off the road. This has little importance on roads.
- The vulnerable parts of drive shaft are covered by thick tube. The whole system is extremely reliable, however if a problem occurs, repairs are more complicated.
- Modular system is enabling configurations of 2, 3, 4, 5, or 6-axle vehicles with various wheel bases.[3]

Disadvantages

- Manufacturing the backbone chassis is more complicated and more costly. However the more axles with all wheel drive are needed, the cost benefit turns in favor of backbone chassis.
- The backbone chassis is heavier for a given torsional stiffness than a uni-body.



The chassis of Tatra 11, year 1923

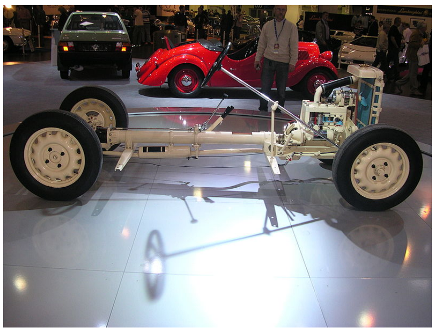
See also

- Tatra concept
- Frame (vehicle)
- Body-on-frame
- Chassis
- Coachwork
- Monocoque
- Spaceframe
- Subframe
- Superleggera
- Swing axle

The chassis of a Lotus Esprit.

External links

- Comparison of standard ladder chassis and backbone chassis with half axles on offroad testing track with emphasis on the twist of superstructure (video):
  - Ladder chassis [4] (Renault fire engine)
  - Backbone chassis [5] (Tatra T815 fire engine)



The chassis of a Škoda 420 Popular.

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