

Chapter 2

Body and Car Architecture

The structure of early cars consisted in a chassis and a body.

The chassis was the main structural frame on which all mechanical components, such as the engine, transmission, suspensions and steering system, were mounted. It was stressed by relevant reaction forces due to all these concentrated loads. The body was the container defining space for passengers and luggage; in early cars it was mounted on the chassis like the other mechanical components while, in modern cars, it is integrated with the chassis, contributing in this way to structural strength and stiffness of the vehicle.

The word chassis, deriving from the French language, has in English a double meaning: it means either the assembly of the structural element of the vehicle or the assembly of the mentioned structural elements plus the mechanical parts that provide to the vehicle motion (suspensions, wheels, steering, brakes, etc.).

In its latter meaning, the chassis is therefore a vehicle subassembly that can be actually available at a given stage of the assembling process, as happened until about the end of the 1940s for most cars, or can exist only virtually, as is the case for more recent vehicles. Nowadays the chassis includes the same components as at the beginning of automotive technology, but it cannot be disassembled as a whole entity from the vehicle.

At the dawn of the motor car era, the innovators who dedicated their intellectual and financial efforts to the development of this new product, concentrated on the components that were more directly involved in the motion of the vehicle, such as engine, transmission, suspensions, steering and braking systems. They became therefore designers and manufacturers of chassis.

At that time body technology was not considered to be fundamental and was directly taken from horse driven carriages and coaches, without significant modifications; many coach builders became body builders, as the first manufacturers of car bodies were called. This situation determined a significant separation between these two industrial branches.

Car manufacturers, or—better—chassis manufacturers, applied mainly metallic materials and were equipped with machines for metal casting, stamping and machin-

ing; because of the precision required, they built parts according to drawings, with tools suitable for batch production.

Body manufacturers applied instead wooden structures or composite structures of steel and wood and were equipped with machinery for working wood or wrought iron components, with tools suitable for single specimens, often copying models, without the help of drawings. This tradition came from the fact that wood was much easier to work than metal and could generate curved shapes, as the current fashion required.

Varnishing, necessary for protecting surfaces from the environment and for giving an acceptable appearance, was another point in favor of wood, taking into consideration the existing oil varnishes. The complete separation of the chassis from the body assembling process was also justified by the need to prevent varnish from being damaged by mechanical components during the complex assembling process.

Several hundreds working hours were required for completing the painting of a car body, only to apply the many layers of varnish; to this figure the drying time of each layer must be added to obtain the total time required for the painting cycle.

The availability of a stand-alone chassis was therefore justified by the existing technology and industrial organization. The chassis manufacturer could thus ship a finished product to the final customer or to a body builder.

A chassis could, in fact, be driven, tested and sent elsewhere; in addition, it could demonstrate its performance to customers also without a body. The temporary test body, shown in Fig. 2.4, had precisely this purpose.

In many cases, the final customer bought a chassis, which was subsequently shipped to the body builder for further works, under a different contract. Nevertheless there were examples of body builders that bought chassis on their own, to sell complete cars, or of car manufacturers that had their own body production capability.

This situation was common until the beginning of World War One.

The needs of mass production encouraged many car manufacturers to develop their own body design and production capability, under pressure to reduce costs. This favored a smooth transition from wood to steel technology, with hybrid wood-steel structures.

The introduction of synthetic enamels, in addition, shortened the painting time by an order of magnitude and favored a deeper integration between chassis and body assembling.

This new organization was developed mainly in the United States and imitated by the major manufacturers in Europe, starting from the beginning of the 1920s. About 20 years later, the first unitized bodies started to be applied in Europe.

The evolution of chassis and body can be described by considering three partially overlapping periods, including respectively the separable chassis, the partially integrated chassis and the unitized bodies.

A following section will be addressed to describe the exterior shape evolution and its influence on aerodynamic performance. The last section will supply a summary about car architecture evolution.

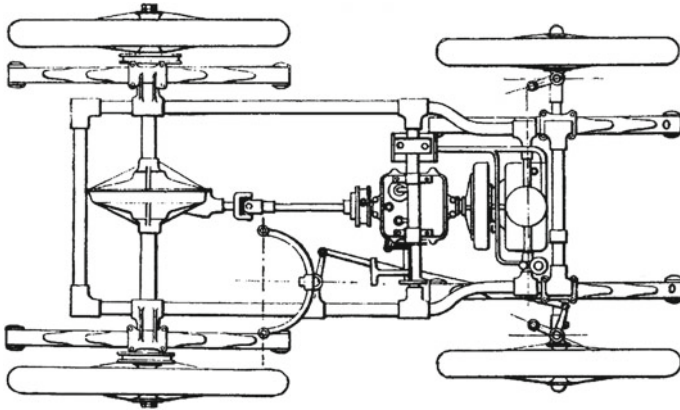


Fig. 2.1 The steel tubes chassis of the 1899 Renault Type A (Courtesy of Renault)

2.1 Separable Chassis

The chassis, in its structural meaning, was the bearing structure of a vehicle and had to support all mechanical components and the complete body that in this case was only a ballast without any particular structural function. In addition, the chassis had to offer an easy organization of the assembling process, being practically the mounting fixture for all mechanical components.

Many of the first car chassis were based on the existing technology developed for bicycles. The 1899 Renault shown in Fig. 2.1 offers an example of this solution. This kind of frame was made with pieces of seamless steel tubes that were cut and bent to their final shape; the different pieces were joined to iron shells with layers of brazing material and cooked in an oven; these iron joints are shown in the figure at the corners of the chassis and where cross beams are joined to the two longitudinal beams.

A second, completely different, solution was applied in the 1907 Sizaire and Naudin, shown in Fig. 2.2; this car is characterized by a chassis made with solid wooden beams, with iron reinforcements, although the body is covered by curved and bent steel panels. There is no apparent reason to explain this strange choice. We could argue that the manufacturer had a previous experience in wooden horse coaches chassis, while it was found easier to use steel panels for exteriors because they could avoid the use of wooden skeletons.

A third solution, used for instance by the Panhard & Levassor firm in its first cars, applied wooden beams covered and reinforced by a thin steel sheet layer nailed on them.

As soon as the weight of mechanical components increased for the application of the first four cylinder engines, the so called *grillage* structures were developed, as shown in Fig. 2.3, where an example of chassis of the beginning of the twentieth century is shown. The chassis was made by two longitudinal beams, made with

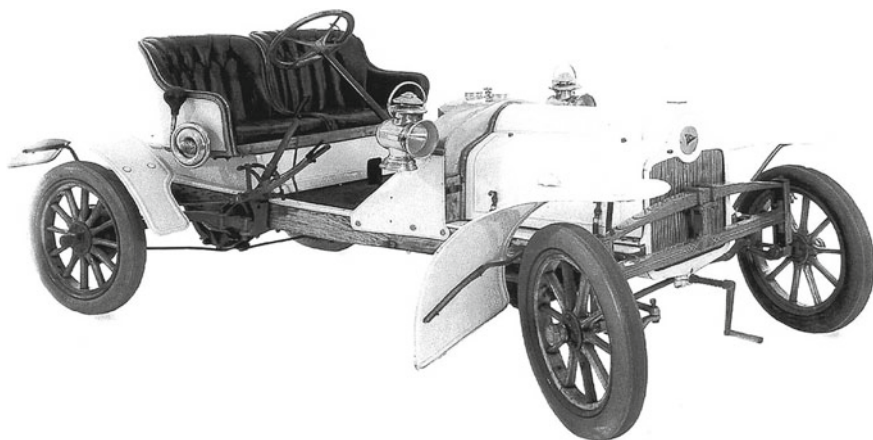


Fig. 2.2 The 1907 Sizaire and Naudin had a chassis made of wooden beams (National Automobile Museum of Torino)



Fig. 2.3 Typical grillage chassis of a car of the beginning of the twentieth century, made of stamped steel (from Morello et al. 2011)

stamped steel with a C cross section; the distance between the two longitudinal beams was reduced in the front part of the vehicle to make steering easier, while it was increased in the rear part to offer a more suitable interface with the body. These width variations were obtained either by bending longitudinal beams or by applying them according to a trapezoidal scheme.

The front and rear ends of the longitudinal beams were bent also in the vertical direction, to leave clearance for suspension motions and were tapered to take advantage of the decrease of bending moment in terms of weight reduction. These curvatures were increased in more recent cars, to lower the floor between the axles.

The two longitudinal beams were joined by bolts to a number of cross beams that built the grille structure; also cross beams were bent to allow space for the engine and gearbox. Cross beams were generally positioned where the most relevant loads, such as engine and gearbox, or the suspensions were applied.

Car bodies used with these chassis were quite similar in shape and technology to those of horse coaches. The body shapes in use were many, as shown in Fig. 2.4 where the shapes in use during the 1920s are listed; their names derived directly from the corresponding ones used for horse driven coaches.

Early cars were open, such as phaetons, spiders or torpedoes; only in 1899 Renault had the idea of introducing a covered car, a sedan with internal driving seat. Closed

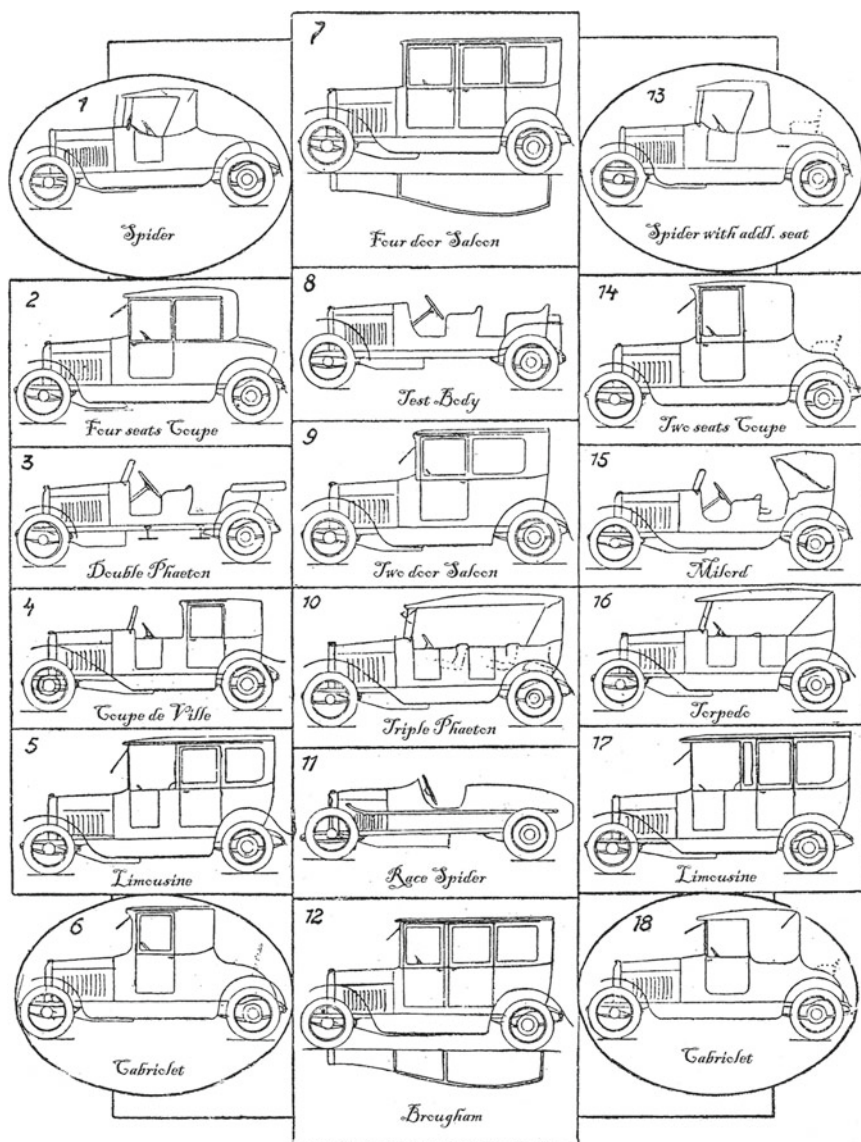


Fig. 2.4 Typical car bodies from the beginning of the twentieth century: (1) Spider, (2) 4 seat coupé, (3) Double phaeton, (4) Coupé de ville, (5) Limousine, (6) Cabriolet; (7) 4 door saloon, (8) Test Body, (9) 2 door saloon, (10) Triple phaeton, (11) Race spider, (12) Brougham, (13) Spider with additional seat, (14) 2 seat coupé, (15) Milord, (16) Torpedo, (17) Limousine, (18) Cabriolet (from Morello et al. 2011)



Fig. 2.5 Coach during the fabrication process, before exterior panels were assembled (from Morello et al. 2011)

bodies represented 20 % of the market in 1920; this percentage grew up to 80 % in the following years maintaining a dominant position until now.

The body fabrication technology used on the early cars was the same as that used in coach building. Figure 2.5 shows a picture taken at the beginning of the twentieth century illustrating a coach during the fabrication process, before exterior panels were assembled. The complex skeleton is made by shaped beams, cut from solid wood boards and assembled using mortise and tenon joints; the picture shows the coach before assembling exterior panels.

These panels, like the interior ones, are made with thin plywood with pronounced curvature. The curvature of the panels is obtained by bending them in place after they had been weakened with a jet of steam; glue and nails allowed them to keep the final shape. This manufacturing technology allowed very rigid and light structures to be built with curved shapes complying with the current aesthetic rules.

The wooden skeleton had not only a structural function but it was the fixture used to model the skin to its final shape.

The drawings of these parts were quite basic, sometimes made directly on the wooden boards; if many equal parts had to be manufactured, the first of the batch was made with hard wood, such as mahogany, to be used afterwards as a template to draw the following samples.

Panels with double curvature could be made with planks nailed on formers and shaved to their final shape as in wooden boats. This kind of body style was named *bateau* after the French language; the phaeton in Fig. 2.4 can supply an example of this style. Each piece of the body had to be adapted in place to the neighboring elements; joints were hidden with plaster and varnish or with profiles, according to the different styles.

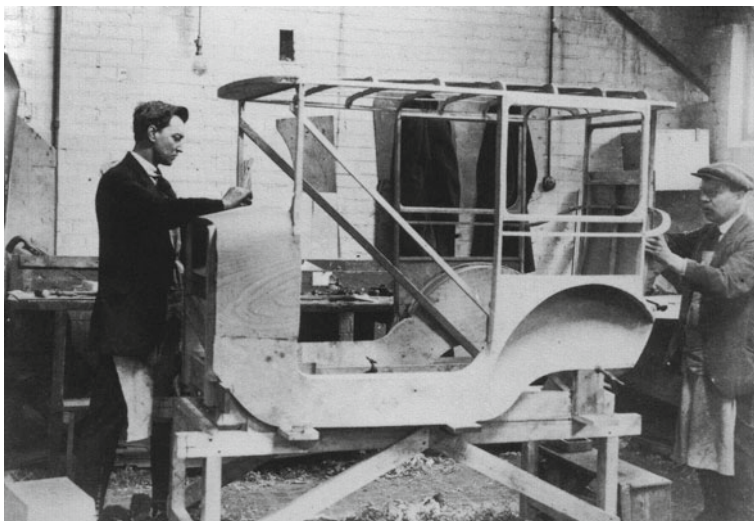


Fig. 2.6 The wooden beams of the skeleton were placed under the skin, where significant curvature changes were present and according to a scheme of ribs and formers (from Morello et al. 2011)

The wooden beams of the skeleton were placed under the skin where there were significant curvature changes, as shown in Fig. 2.6 and according to a scheme of ribs and formers, as in the same figure in the roof area. Ribs and formers were applied under the areas of higher curvature, such as the roof, the rear closure and the transition surface between the body sides and the hood. The roof cover was often made with a sheet of pegamoid, as it will be later explained for Weymann bodies.

The torsional stiffness of grillage chassis was quite low, roughly determined by the sum of the torsional stiffness of each of the two longitudinal beams, considering the limited contribution of cross beams. The torsional stiffness of each longitudinal beam was itself low, due to their open cross section. On the contrary, the torsional stiffness of a new wooden body was significantly higher, in consideration of the kind of joints used in carpentry, such as dovetail joints or mortise and tenon joints.

The significant deformations of the flexible chassis induced premature cracks and ruptures in the joints of the body, due to the higher stiffness of the latter. In fact, body and chassis are two flexible structures put in parallel subjected to equal displacements in their joints; the stiffer the element connected to the joints, the larger the stress.

Wood joints could not bear very high loads and increased their clearances: this produced annoying squeaks and rattles; in addition, a car parked on an uneven road could make door opening difficult.

Increasing the torsional stiffness of the chassis became an important issue for its effects on the body; the problem became more relevant with the increase of the speed cars could reach. The remedies to this problem followed two opposite strategies: To increase the body stiffness or to make its deformation less subject to squeaks and rattles.

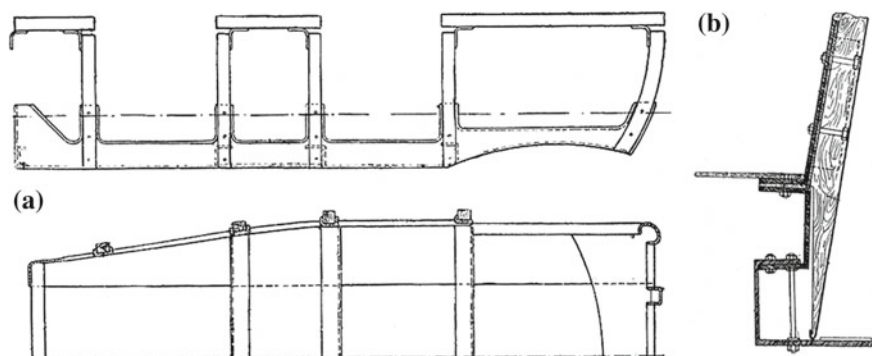


Fig. 2.7 Two opposite remedies to body squeaks and rattles: To make deformation less noisy **a** or to increase the body stiffness **b** (from Morello et al. 2011)

Figure 2.7 shows some details of these two strategies. In Fig. 2.7a the cross section of a body designed according to the first strategy is shown. There was a heavy auxiliary steel frame at the bottom of the wooden body; the frame had an L cross section and was joined to the wooden skeleton. The vertical wing of the L section was bolted to the struts of the skeleton, while the horizontal wing was interfaced with the chassis and supported the wooden boards of the floor. The wooden struts of the body skeleton reached the steel running board, covering the sides of the chassis.

While the body was made much stiffer than the original wooden structure, the joints with the chassis were made flexible with layers of rubber or fibers in between; with such a design the deformation of the flexible chassis was allowed by the joints without major involvement of the body.

An alternative strategy was developed by some body shops, among which Weymann, an airplane manufacturer, was the most famous; in fact this technology is usually associated to his name. He developed his body structure concept during the 1920s, deriving it from the aeronautical technology of that time used to make wings and fuselages.

The body skeleton shown in Fig. 2.7b was still wooden, with beams set at the rims of the body shape or according to a scheme with ribs and formers; the steel joining elements between beams were intentionally flexible and the wooden beams were mounted with significant gaps. With this architecture there was no danger of contacts between wooden parts and of consequent squeaks and rattles.

The body skin was made, as in airplanes, with a layer of cloth, covered with a waterproof varnish, having the appearance of leather and called pegamoid or leatherette. Hood covers and firewall were made of steel or aluminum, as in other bodies for reasons of resistance to heat. This kind of body manufacturing technology was particularly appreciated for sport cars because of the reduced weight.

The technologies explained above refer to the time period till the end of the 1920s; in the following decade intensive use of steel started to spread, making possible different design solutions.

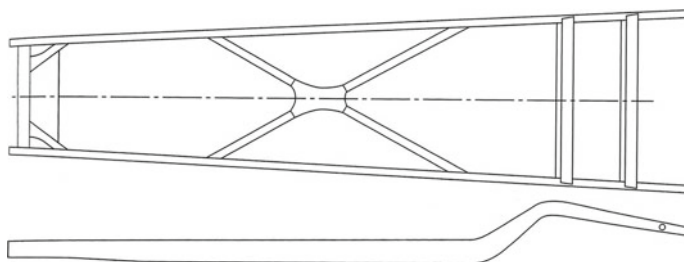


Fig. 2.8 Stamped steel chassis with an X cross beam (from Morello et al. 2011)

2.2 Partially Integrated Body and Chassis

In partially integrated architectures the body and the chassis are bolted together, with an increase in the bending and torsional stiffness of the car; the assembling cycle can remain the same as in previous case, with a complete body mounted on a complete chassis at the end of the assembling line.

Some of the chassis of the 1930s were developed according to a configuration different from grillage schemes; in particular the application of *X cross beams*, as shown in Fig. 2.8, introduced a significant improvement in the stiffness performance.

The X cross beam, that was usually riveted to the longitudinal beams, because of its shape, reacted to chassis torsion by bending; this is easily understood because the longitudinal beams are no longer parallel when twisted and this causes the X cross beams to bend. Since the flexural stiffness of cross beams is larger than their torsional stiffness, the chassis overall torsion stiffness is increased.

A further improvement to this architecture was given by a chassis with only one central longitudinal beam, having a closed cross section; this became feasible with the introduction of large stamping presses and of welding in the manufacturing shops. *Central beam* chassis have not only an advantage for the increased stiffness of closed cross section, but also for the possibility of reducing floor height with a consequent improvement in car weight and roll-over resistance. A chassis of this kind is shown in Fig. 2.9.

Steel stamping allowed any part of the chassis to be designed to withstand local stress, again with a better control of the weight; the only disadvantage was the impact on investment cost due to the larger amount of stamps and presses necessary to the manufacturing process.

Rear driven cars with the engine in the front had the transmission shaft installed inside of the central tubular beam. With older architectures, also cross beams had to be bent to clear the bulk of the transmission shaft.

This kind of stiffer chassis could now be bolted directly to the body, made mostly of steel, because the torsion stiffness of both parts was better balanced; the result so obtained was a good increase in the vehicle overall stiffness. Also large steel panels were now feasible thanks to the availability of large presses.

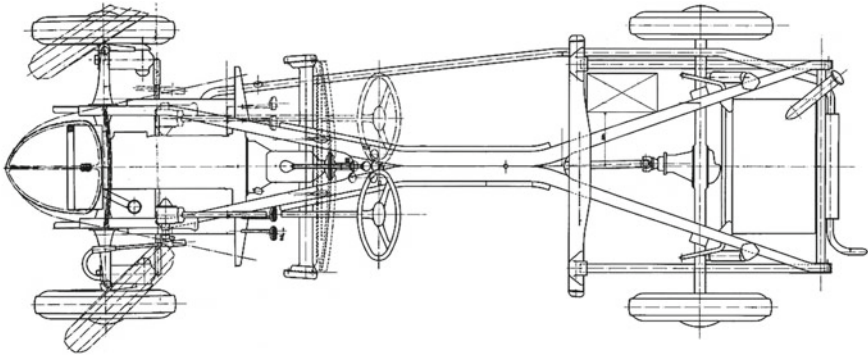


Fig. 2.9 Chassis with central tubular beam; all chassis members feature closed cross sections (Courtesy of FIAT Historical Archives)

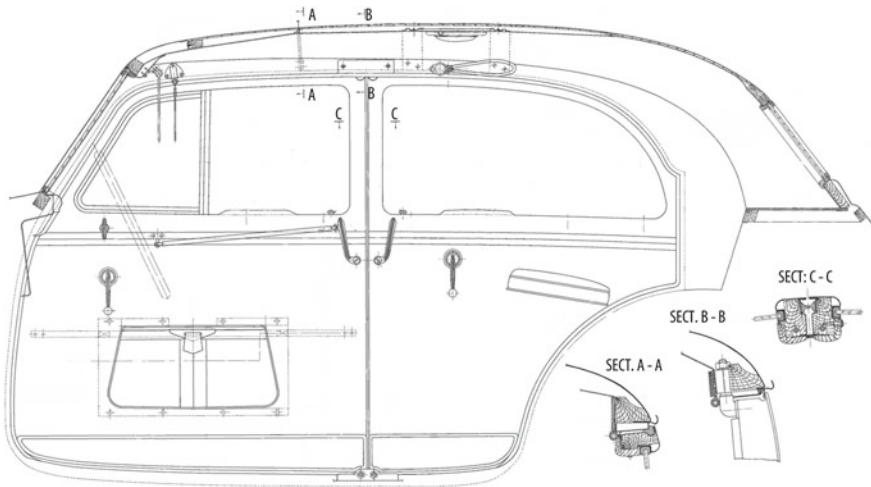


Fig. 2.10 Body structure made with wooden skeleton and steel panels. Notice the wooden elements in cross sections (from Morello et al. 2011)

Two alternatives were developed for partially integrated steel bodies. In the first the steel skin of the body was joined to a wooden skeleton with wood screws. The function of the wooden beams was double: to reduce the shape instability of the thin sheet panel and to offer an easy attachment for the internal trims and upholstery. The shape of the steel panels could be simple, being reduced to portions of the exterior shape, with small flanges at their contour to be bolted to the wooden skeleton. An example of this kind of body architecture is shown in Fig. 2.10a.

For aesthetic reasons, screws were set only where they could not be seen from the outside, i.e. at the external contour of doors and on door posts.

A second alternative, introduced in the same period of time, was characterized by a body skeleton made also of stamped steel sheets and more complicated flanges, at the contour of body panels. Also in this case, the body was bolted to the chassis.

The contemporary existence of these two architectures today might seem difficult to understand, but the explanation is again linked with cost and production volumes. The all-steel solution was typical of large production volumes, to absorb the impact of a larger expense in stamps and presses. At the same time, the low salaries of that time did not discourage the application of more complicated wood and steel structures, in case of small production volumes, because of the advantage of reducing investments.

The structural adequacy of the two alternatives was almost equivalent, with the advantage, in case of wood, of a better corrosion resistance; in fact, many 60 years old cars with a skeleton of ash-wood are still kept in good shape by collectors.

Till the end of the 1940s, luxury sedans, sport cars, station wagons and vans had this kind of body architecture; many fashionable station wagons of this time (called familiarly Woodies) had also part of the exterior panels made of natural wood.

This intermediate solution of partially integrated body and chassis may be justified by remembering that the manufacturing process was organized with chassis and body shops in different locations; a fact that delayed the introduction of unitized bodies. In addition, the non integrated solution was preferred because different bodies could be installed on the same chassis, with positive impact on investments, and wealthy customers could continue to obtain separate chassis for their custom-made bodies.

2.3 Unitized Bodies

The integration of body and chassis in a single unit was considered as the best chance to improve the structural performance, with reductions in weight and cost. In closed bodies, like those of sedans or limousines, the distance of the roof from the longitudinal beams allowed building of a very stiff structure, provided that these element were joined by other vertical structural elements (pillars) stiff enough and well fitted in the joining points. In addition, if the body skin panels were suitably stamped, they could further increase the stiffness of the skeleton by their resistance to shear.

Probably the first attempt to develop such an architecture was done with the 1922 Lancia Lambda; its structure without exterior skin, but complete with all mechanical components, is shown in Fig. 2.11. The body structure is made with steel panels about 2 mm thick, obtained by milling and bending; they are joined with a variety of joints, including rivets and continuous and spot welding.

The sides were made with reticular beams; many structural elements were set above the large sills (in fact, door dimensions are limited) and increase the overall structure stiffness, in comparison with traditional chassis.

The contribution to the overall stiffness of the sides is increased by very rigid cross diaphragms, corresponding to the dashboard, the seat back rests and the tail. The front suspension is connected to the body with a tubular portal structure, surrounding the

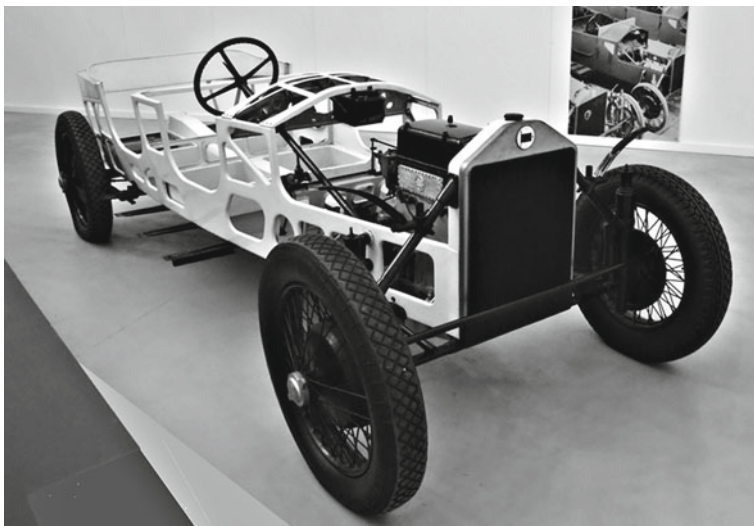


Fig. 2.11 The 1922 Lancia Lambda body structure integrating chassis function (National Automobile Museum of Torino)

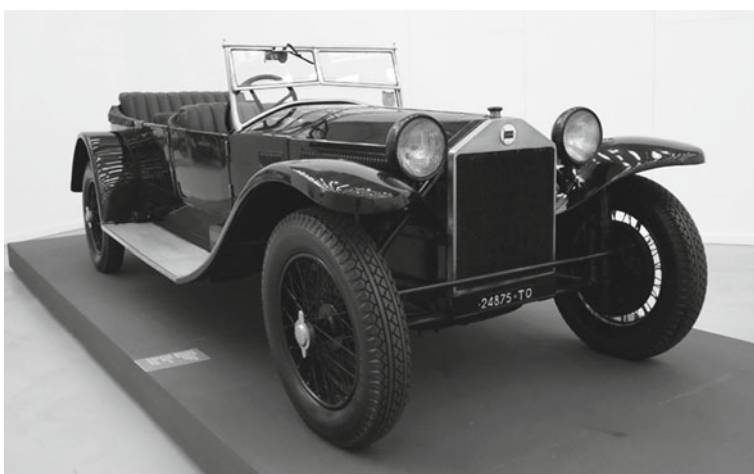


Fig. 2.12 The body of the 1922 Lancia Lambda was very low over the ground, thanks to the integration of the chassis function (National Automobile Museum of Torino)

radiator, that contributes further to the stiffness. Welded panels covered the skeleton with further increase of bending and torsional stiffness even if the use of rolled and bent components prevented obtaining of very stiff closed cross sections.

Apart from the structure performance, the impact of this new architecture on the body volumes layout is immediately clear from Fig. 2.12: the body rides much lower

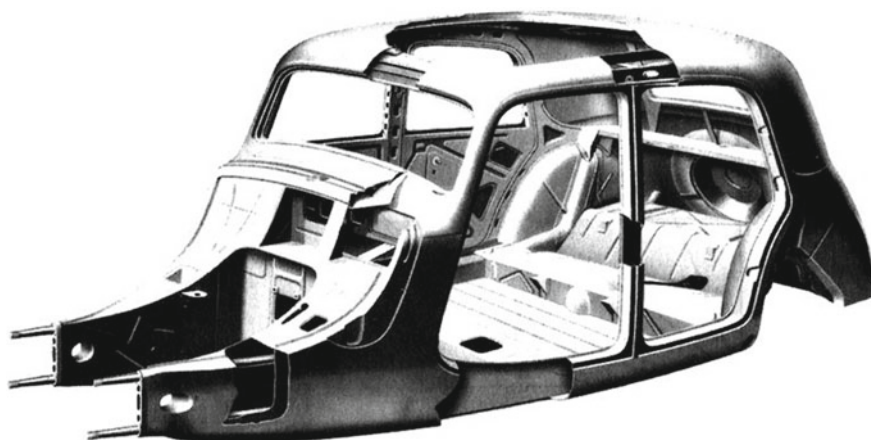


Fig. 2.13 Unitized body of the 1934 Citroën 11 CV (from Morello et al. 2011)

on the ground. The patents of Lancia included also the transmission tunnel that gave a significant contribution to height reduction, with positive impact in aerodynamic and handling performance.

It must be pointed out that the success of this car was affected by the fact that body builders were not equipped for this significant change in aesthetics; in the following cars, Lancia offered a specific traditional chassis for custom-made bodies, and a factory-made unitized body as an alternative.

The structure designed by Lancia at that time was suitable for torpedo bodies only; sedan bodies were obtained by adding a Weymann top cover (*ballon*), without contribution to stiffness. A further step was made about 15 years later with a more extensive application of spot welding and of deep stamped steel sheets.

One of the first examples of a very effective structural integration between body and chassis is offered by the 1934 Citroën 7, 15 and 11 CV, whose body is shown in Fig. 2.13. This car is also the first application on large production volumes of the front wheel drive scheme. All steel panels of the body have particular shapes, suitable to build up stiff closed sections by welding them along the flanges. The result was a structural cage, including sills, pillars and roof beams.

The sills integrate, in their front part, flanges to which the powertrain and the front axle were assembled. Also roof beams show a closed cross section, as it can be seen in Fig. 2.14; the aesthetic damages of spot welding on the roof panels were masked by filling with melted tin, that was then polished.

The chassis did not exist anymore as a physical element, nor it could be separated from the body, without destroying the welds. This completely changed the assembly cycle and body shop organization in comparison with the past. The unitized body was welded and then painted and only later the mechanical subsystems of the chassis could be mounted on the painted body. Low volume custom-made bodies became now very expensive, because the body shop could take care also of the complete car assembly.



Fig. 2.14 Roof structure of the Citroën 11 CV unitized body (Picture taken at Rétromobile, Paris, 2009)

2.4 Aerodynamic Performance Evolution

It is incorrect to state that aerodynamic performance was completely neglected in the early cars, as their squared shape could suggest.

The control of the aerodynamic drag had been imported from shipbuilding industry; design criteria were however naive, for lack of experimental data or calculation procedures. Some cars show a particular attention to this problem; among them the *Jamais Contente*, an electric car with a torpedo like shape, the first to exceed a speed of 100 km/h in 1899 and the Alfa Romeo 40–60 HP, with the body designed by Ricotti, shown in Fig. 2.15.

Both bodies were inspired to the slender body shape, the shape sporting the minimum drag resistance in a uniform airflow. These shapes were premature with reference to the real customers' needs and not suited for building a vehicle; the advantages that could be obtained were practically useless (the Ricotti's car claimed an increase of top speed from 125 km/h, of the standard car, to 139 km/h).

Five sedans made by FIAT are shown in Fig. 2.16 to illustrate the aerodynamic evolution of car shapes. In the early period, up to 1915, the body shapes were squared, particularly in the front, where the hood joined the firewall below a flat windshield; an example being the 1908 FIAT 35–45 HP, shown in Fig. 2.16a. This shape was the direct consequence of the manufacturing technology used.

The 1919 FIAT 501 shown in Fig. 2.16b is representative of a new style, typical of the period between 1915 and 1930. Shapes are now more rounded and show the changes that can be obtained by the use of steel sheets instead of wood. The surfaces have simple curvature, feasible with rolling and bending presses; fenders have double curvature and are obtained by beating sheets by hand on open stamps.

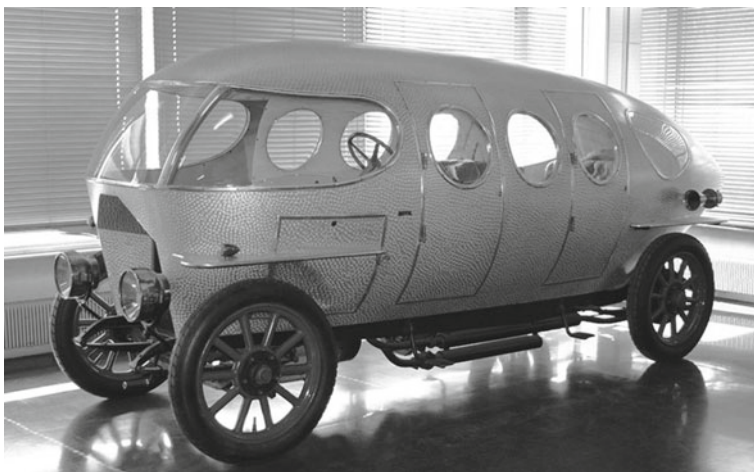


Fig. 2.15 The streamlined body of the Alfa Romeo 40–60 HP designed by Ricotti (Alfa Romeo Museum at Arese, Italy)

There is a continuous profile between the hood cover, the cowl and the body sides; the radiator too is rounded at its edges.

A completely new style is shown by the 1934 FIAT Balilla Sport Berlinetta, (Fig. 2.16c); this is the first body developed according to systematic studies of the aerodynamic behavior, performed partly in an aeronautical wind tunnel, partly on the road directly. The windshield inclination was optimized on the road, with an increase of top speed of 5 % around 100 km/h. The hood profiles are completely aligned with those of the body sides; the windshield and the radiator are inclined. Each corner is rounded and the shape of the body is tapered at the front and tail end. The fenders tend to be integrated into the body sides.

Many studies of this kind were performed in Europe at this time; those conducted by Lay in the United States in 1933 are still interesting today, showing the effect on aerodynamic drag of many different body arrangements.

The leader of the revolution of the streamlined design was the famous 1934 Chrysler Air Flow, shown in Fig. 2.17, that however was not received by the public with enthusiasm.

The 1935 1500 (Fig. 2.16d) is the reinterpretation, given by FIAT's stylists, of this streamlined design and show further improvements of the shape of the Balilla, such as the headlights in the fenders and the rounded radiator; this is one of the first cars with an aerodynamic coefficient lower than 0.5.

The chart plotted in Fig. 2.18 shows the evolution of the aerodynamic drag coefficient as function of the decade of commercial launch, representing with bars the best and the worst value. Tests are recent and made in the same wind tunnel.

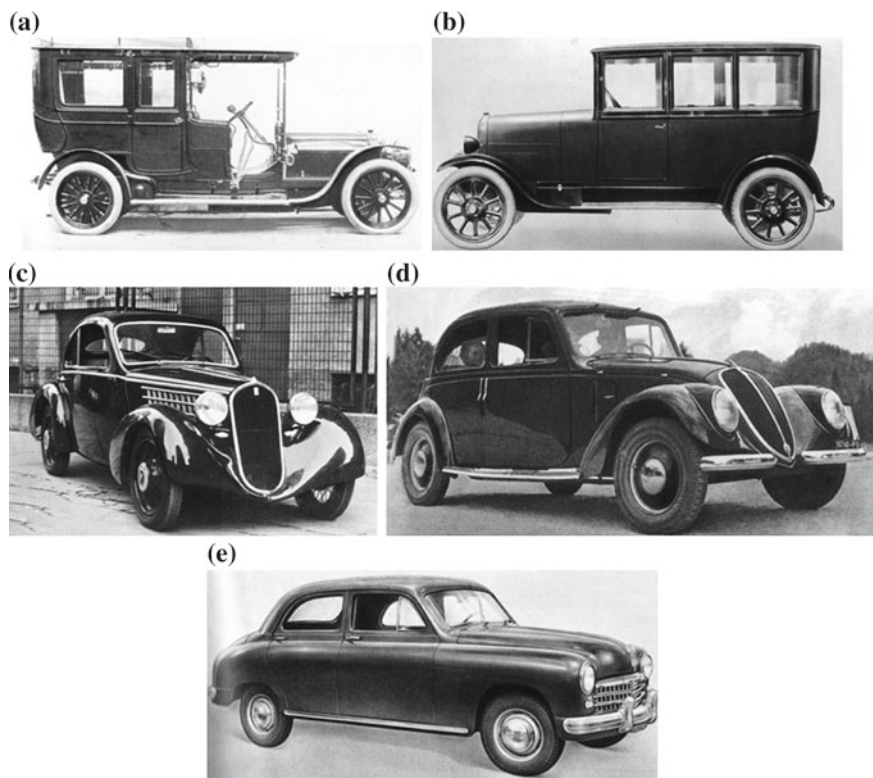


Fig. 2.16 Main milestones of the evolution of the car body shape, shown by some FIAT sedans (from Morello et al. 2011)

The 1950 FIAT 1400 (Fig. 2.16e) is one of the first examples in Europe of the ponton style, where body sides integrate the fenders completely in a single rounded surface; running boards have disappeared.

The oil crisis of the 1970s stressed further more the need of reducing the aerodynamic drag; the new improved aerodynamic performance is not only due to new body shapes, but also to a painstaking care to many small details of the outer surface and of the underbody.

2.5 Vehicle Architecture

Vehicle architecture may be defined as the lay-out of the main components, such as engine, gearbox, transmission, axles, etc. Also in early cars space was never enough and an unsuitable lay-out could easily sacrifice the volume available for the passenger compartment.

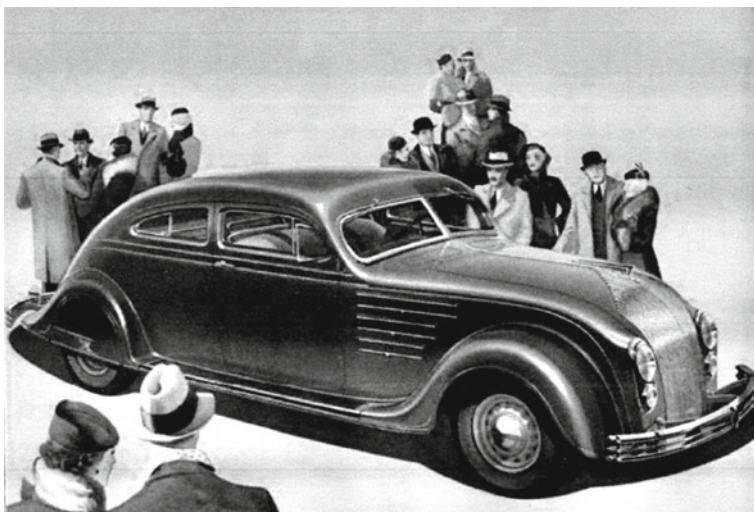


Fig. 2.17 The 1934 Chrysler Airflow (from a Chrysler's Catalog)

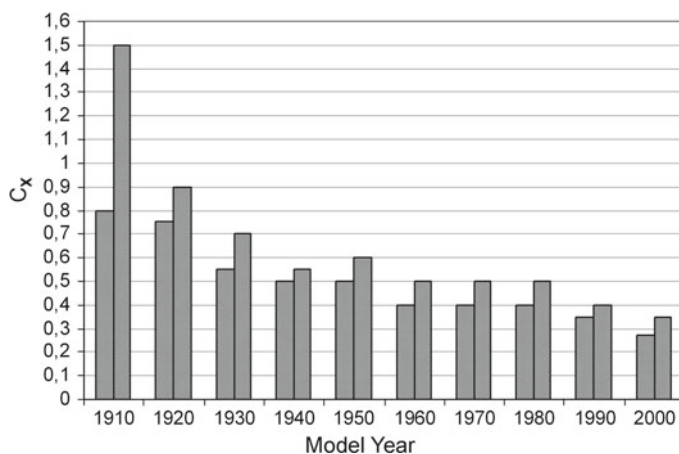


Fig. 2.18 Evolution of the aerodynamic drag coefficient as function of the decade of commercial launch. The best and the worst value for each decade are shown (from Morello et al. 2011)

By considering only the main features and neglecting for simplicity the shape of the body, the vehicle architecture can be identified as follows:

- The number of wheels;
- The position of the driving axle;
- The position of the engine;
- The kind of mechanical linkage between engine and wheels;
- The position of the passengers.

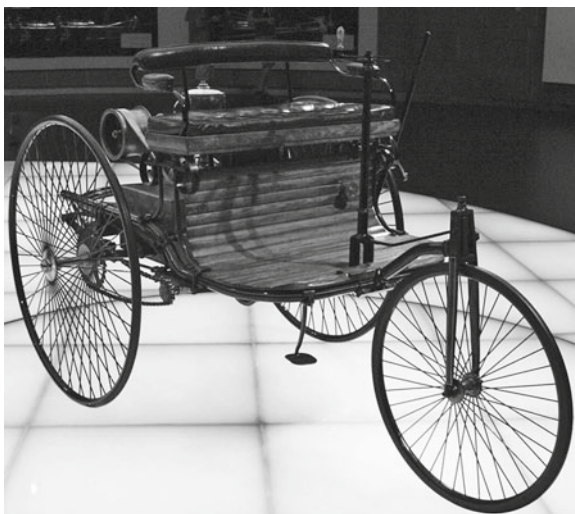


Fig. 2.19 The 1886 Benz Patent Motorwagen tricycle (Mercedes-Benz Museum, Stuttgart)

Apart from two wheel vehicles not considered in this book, the majority of ground passenger vehicles were and are provided with four wheels, organized in two axles, except for some of the earliest vehicles that were based on a three-wheels architecture.

The first motor car (meaning the first car manufactured for sale and not for scientific experiments), the Benz Patentwagen, was a tricycle indeed, as it was the first Italian car (Bernardi) and the first best seller on the French market (De Dion-Bouton). The tricycle option introduced some simplification in the steering mechanism, if the single wheel was placed at the front axle, as in the 1886 Benz Patent Motorwagen. In this way the steering motion of the wheel was cinematically correct by definition and the related control was simple, as can be seen in Fig. 2.19

If the single wheel was placed as a rear driving axle, the transmission could be simplified avoiding the differential, as in the case on the 1894 Bernardi, (Fig. 2.20).

In addition, a tricycle was a statically determined system in its interface with the ground: The forces acting between wheels and ground are univocally determined by the position of the centre of mass and these forces are, within certain limits, independent from the ground, that is never flat nor horizontal.

As a drawback, the effect of the centrifugal force in a curve or of the lateral slope of the ground could impair the roll-over stability of the vehicle. Mainly for this reason, four wheels vehicles were eventually preferred, despite their complication.

The application of four wheels made the vehicle statically undetermined, i.e. the forces on the ground cannot be computed without taking into account local deformations; moreover, a rigid link between wheels and vehicle could produce loss of contact between one wheel and the ground, if the latter is not perfectly flat.

Daimler, with his 1889 Stahlradwagen (Steel Wheel Car), shown in Fig. 2.21, tried to bypass this obstacle by mounting the front axle on a tilting beam, like a



Fig. 2.20 The 1894 Bernardi tricycle (National Automobile Museum of Torino)



Fig. 2.21 The Daimler 1889 Stahlradwagen (Deutsches Verkehrsmuseum in Munich)

balance, able to compensate for the effect of uneven ground. However, in this way the lateral stability was equivalent to that of a tricycle, having a front single wheel in the position of the hinge of such a balance.



Fig. 2.22 The 1769 Cugnot's Fardier (Conservatoire National des Arts et Métiers in Paris)

This is the reason why elastic suspensions were introduced, not only for reason of comfort, but also to keep all wheels in contact with the ground (see Appendix B.5).

Restricting to two axles vehicles, with a single driving axle, it is possible to identify the following architectures, which are listed roughly in chronological order:

- Early front-wheel drive vehicles with front engine;
- Early rear-wheel drive vehicles with rear engine;
- Early rear-wheel drive vehicles with front engine;
- Evolved rear-wheel drive vehicles with front engine;
- Evolved rear-wheel drive vehicles with rear engine;
- Evolved front-wheel drive vehicles with front engine.

Because horses were hitched in front of the carriage, it looked natural to many inventors to install the engine in the front part of the vehicle. The first motor vehicle, the 1769 Cugnot's Fardier (Truck) had a front driving wheel with the steam engine and the boiler rigidly mounted on the front steering wheel, as shown in Fig. 2.22.

Later, some motor-axle assemblies were developed, to replace directly the front axle of a coach; some of these motor-axles (with electric, steam or internal combustion engines) were still available at the end of the nineteenth century, to convert existing horse driven vehicles to the new technology. An example of this approach is shown in Fig. 2.23.

Locating a heavy mass, like an electric motor and its batteries, without any kind of suspension obviously caused problems of discomfort and severe limitations to the maximum attainable speed. When installing the engine on the suspended body and considering the problems linked with the transmission of the power to the driving wheels, it was more expedient to have the rear non-steering axle as the driving axle. At any rate, it was necessary to develop some mechanical transmission device allowing to connect two elements (engine and axle) that could move with respect to each other.

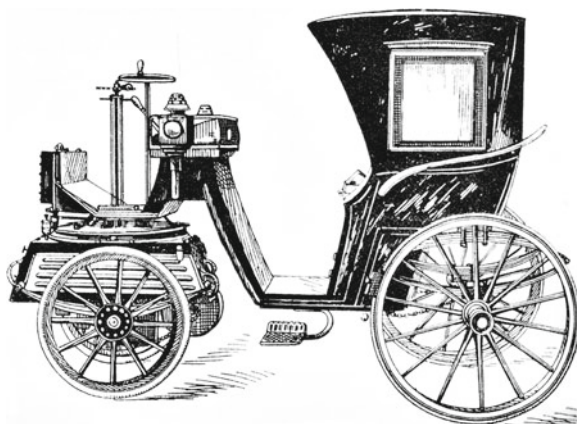


Fig. 2.23 An example of a horse driven coach transformed with an electric front axle (redrawn from Pedretti 1908)

It looked also easier to place the engine in the rear, not only because it was closer to the driving axle, but also to leave a better visibility to the driver. If the engine was placed in the back, seats were set in a *vis à vis* (face to face) arrangement; if it was in the middle, in the *dos à dos* (back to back) arrangement; both architectures were already applied to small coaches (*vis à vis* and dog-carts).

An architecture of this first kind is shown in Fig. 2.24, depicting the 1890 Benz Victoria, whose engine is installed in the back of the car and transfers its motion to an auxiliary shaft, in the middle of the vehicle, through a couple of leather belts. These belts acted as a two speed gearbox and also as a clutch. The auxiliary shaft contained the differential mechanism, needed to drive the rear wheels at different speeds.

The transmission between the auxiliary shaft and the wheels was made by two chains; since the chain could not change in length, the centre of the auxiliary shaft was coincident with the centre of rotation of the leaf spring, close to its front eye. Similar schemes were applied till the beginning of the twentieth century.

Thanks to the developments of Panhard & Levassor, a more rational solution was identified in 1894, as shown in Fig. 2.25. It consists in a front-mounted engine, that operates, through a clutch and a gearbox, an auxiliary shaft with the differential, followed by a chain transmission to the rear wheels.

A further improvement to this architecture was introduced by Renault in 1899 (Fig. 2.1) with his first car, the Model A; chain transmissions were replaced by a single shaft transmission with two universal joints, while the differential was installed in the axle. This kind of transmission was less vulnerable and easier to lubricate. The imitation of this improved solution by competitors was delayed by the patents that Renault filed to protect his invention.

These two architectures became rapidly common and the latter is still present in some contemporary cars; both approaches allowed placement of two or three rows of seats all fronting the road.

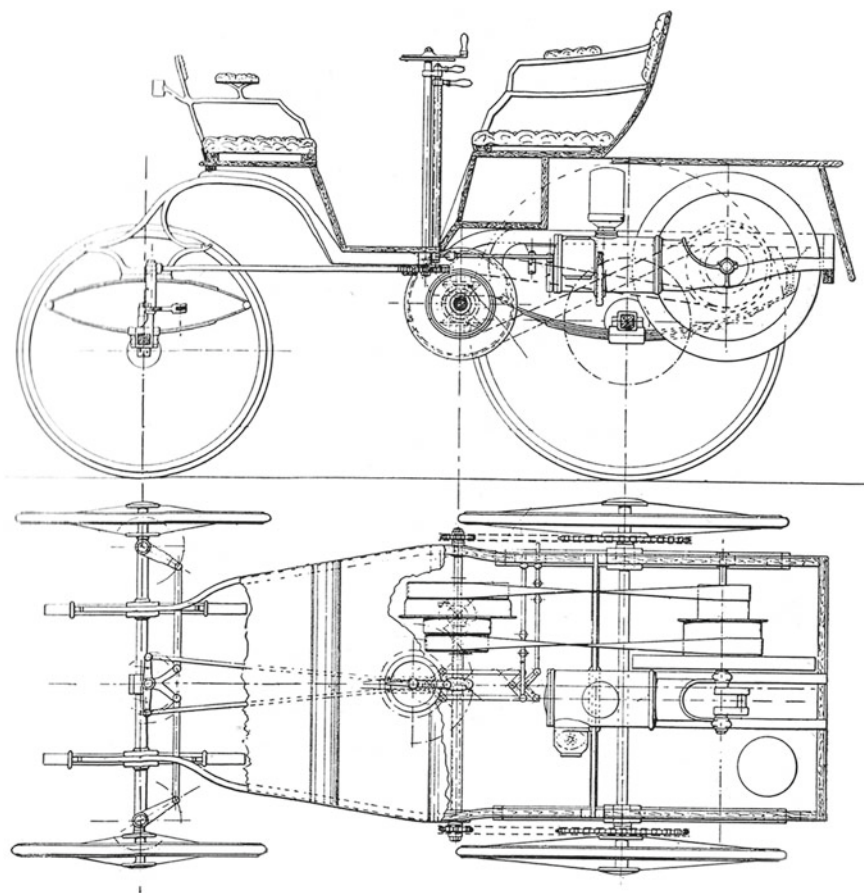


Fig. 2.24 Scheme of the chassis of the 1890 Benz Victoria (Redrawn from Baudry de Saunier 1900)

The transmission shaft has always been an obstacle to obtaining a comfortable passenger arrangement, particularly in small cars that suffered from a floor position that was too high and a small luggage compartment, because of the presence of the differential in the rear axle.

A good improvement to this situation was obviously to concentrate the powertrain on the driving axle, avoiding the transmission shaft; the first option was to develop rear wheel driven car with rear engine, because joints suitable for steering wheels were not economically available by the time when small cars became interesting. The first attempts were made in the 1930s by Mercedes and KdF (later Volkswagen).

Many small cars with this kind of architecture helped the European economical recovery after World War Two. A well known example is the 1953 FIAT 600, whose

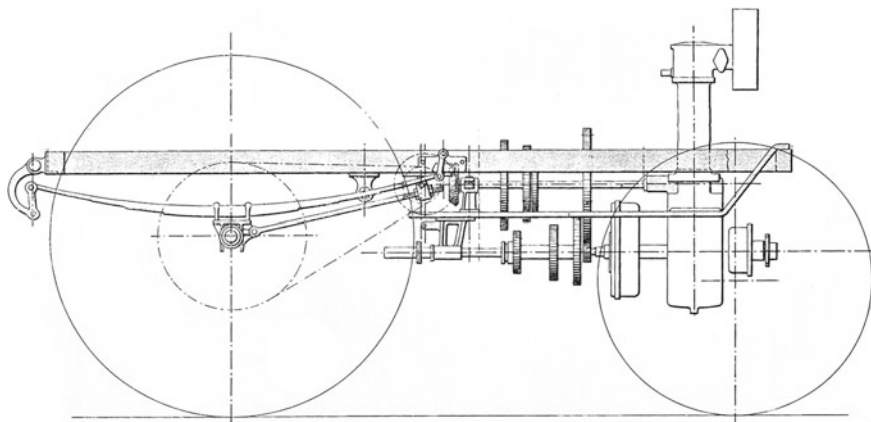


Fig. 2.25 Scheme of the chassis of the 1894 Panhard & Levassor (Redrawn from Baudry de Saunier 1900)

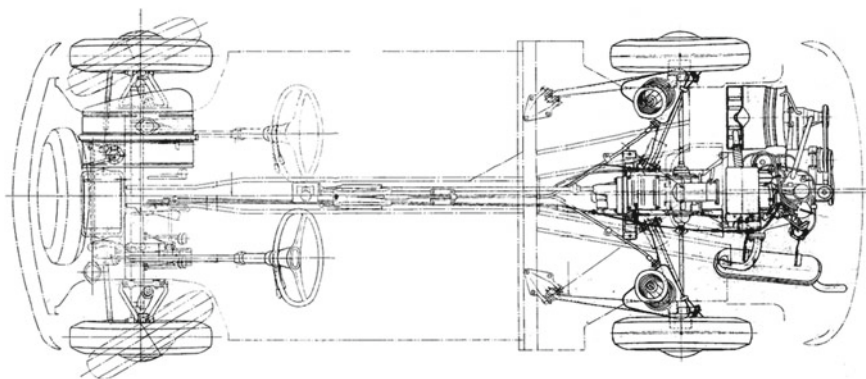


Fig. 2.26 Scheme of the 1953 FIAT 600 (Courtesy of FIAT Historical Archives)

chassis is shown in Fig. 2.26. In a length of about 3.2 m there was space for four passengers and their luggage. This architecture lasted about 40 years, from 1940 to 1980; but at present it constitutes an exception.

The solution that proved more expedient where the internal space is concerned, particularly for the luggage compartment, was obviously front wheel drive with front engine; this architecture was attempted several times without success, and found its conditions of economical feasibility only when some specific components were developed, namely:

- The constant speed ball joints (Ford 1936);
- The Mc Pherson front suspensions (Ford 1948);
- The powertrain with engine and gearbox aligned (Autobianchi 1964).

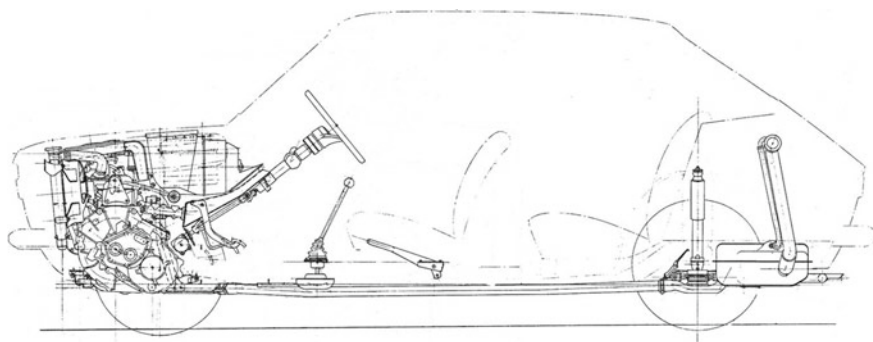


Fig. 2.27 Scheme of the 1971 FIAT 127 (Courtesy of FIAT Historical Archives)

As an example of this architecture, the chassis of the 1971 FIAT 127 is shown in Fig. 2.27; it allows a large passenger compartment with sufficient space for luggage, not too high on the ground. Most contemporary cars are based on this scheme.

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