ALL-EMBRACING MODIFICATION OF A MASS-PRODUCED RENAULT CLIO TO PREPARE IT FOR PROFESSIONAL RALLYCROSS RACING

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Summary

Motorsport constitutes an excellent research laboratory for the entire automotive industry and all the related industry branches. Since the dawn of motorization, motor vehicle component systems have been developed and improved. This process will go on and there is no doubt that it will never stop. Engines with rising performance require increasing strength of transmission system components. The more efficient use of the power transmission system requires improvements in the suspension system, which will ensure better vehicle handling, and higher efficiency of brakes, so that the vehicles moving with higher and higher speeds can be stopped more effectively. An increase in the cruising speeds entails a higher accident hazard and this, in turn, requires safer construction of the vehicle body.

The best way to develop the modifications is to test them in the difficult conditions of professional motorsports. The solutions engineered for this purpose and proven on such a kind of testing ground are afterwards adapted to mass-produced vehicles and used in everyday vehicle operation. This publication is to present the scope of the work to be done when building a high-performance sports car that must meet the requirements of regulations laid down by FIA (Federation Internationale de l'Automobile) for vehicles of this type. The works described in this article were undertaken to modify the construction of a mass-produced Renault Clio car of the second generation in order to adapt it for professional motorsports, chiefly for starts in Polish and international rallycross championships. The modifications of this car intended for rallycross racing consisted in the designing or modernization of its individual parts and component units so that they were compatible with the specificity of this sport and were in conformity with FIA requirements.

Keywords: motorsport, rallycross, Renault Clio, special-purpose vehicle, sports car

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1. Introduction

"There is no doubt about the date people began racing automobiles. It was the date they built the second automobile."[3]

Richard Petty, a racing driver

This sentence fully describes the phenomenon of motorsport. On the one hand, it actually is sport, because it contains such elements as fight against time, rivals, forces of nature, or human weakness. On the other hand, however, it constitutes a powerful research laboratory for the entire automotive industry and all the related industry branches. Since the first engine-driven motor vehicle appeared, an unceasing race takes place between vehicle constructors, who develop better and better and increasingly efficient machines [4].

Each of the motor vehicle component systems has been improved since the dawn of time. This process will go on and nothing indicates that it will ever stop. Engines with rising performance require increasing strength of transmission system components. The more efficient use of the power transmission system requires improvements in the suspension system, which will ensure better vehicle handling, and higher efficiency of brakes, so that the vehicles moving with higher and higher speeds can be stopped more effectively. An increase in the cruising speeds entails a higher accident hazard and this, in turn, requires safer construction of the vehicle body. All the changes of this type may be best tested in the severe conditions of professional motorsports, which are also a good marketing tool thanks to their spectacular value [7].

The solutions engineered with using such a kind of testing ground are afterwards adapted to civilian vehicles, which can be seen in car showrooms and which are used for everyday purposes. However, the need to improve motor vehicles is the domain of not only great automotive manufacturers [3]. The development of motorization is also stimulated by independent constructors, whose vehicles proved many times to be spectacular successes and many of their solutions are used by the automotive industry in everyday production [18].

This article shows the process of building from scratch, according to a precisely defined design basis, a high-performance sports car for a specific motorsport, based on a mass-produced body. The main technical specifications of this vehicle have been compared with those of the base vehicle model, commercially produced; the said comparison makes a summary and benchmark for a preliminary assessment of the work results achieved.

[3] After "The Daytona 500: The Thrill and Thunder of the Great American Race" by Nancy Roe Pimm, Millbrook Press. Translator's note.

2. Design basis for the project

The following requirements were adopted as a design basis to characterize the modified vehicle construction compared with the base vehicle model.

- The vehicle will be used in the cycle of Rallycross European Championships; therefore, it must be in conformity with the FIA regulations for this cycle of events.
- Apart from the factory-made parts used for the vehicle construction, the maximum possible number of vehicle components should be made by Polish manufacturers.
- The final market value of the car should not exceed EUR 60 000 (to be competitive for the western constructors).
- The vehicle should be based on the Clio II model (of the second generation), made by Renault (visually close to the Clio S1600 model made by the Renault motorsport division).
- The vehicle should be front-wheel driven (FWD), with a possibility of modification to a rear-wheel drive (RWD) or all-wheel drive (AWD) version (enabling a change of the vehicle class, if necessary).
- The engine should be of up to 2 litres capacity (because of the availability of a factory-made prime mover in a motorsport version, normally aspirated or turbocharged).
- The vehicle mass should be minimized (because of the significant impact of mass on the vehicle performance).
- The performance characteristics should be maximized (by appropriate preparation or modification of the subassemblies used).
- The maintenance and servicing should be facilitated (by application of innovative engineering solutions that would streamline the servicing an reduce the costs of repairs).

The above requirements, although seeming to be quite vague, actually define very precisely the final features of the finished car.

3. Modifications of the car body

Significant modifications of the base vehicle's body were planned. For the modifications to be made at a high level of professionalism, much of preparatory work was necessary. In particular, the base vehicle had to be completely dismantled, any protective and paint coats had to be removed, and the vehicle body had to be precisely measured for the reasonability of starting the construction work on the specific body to be confirmed. Furthermore, the unnecessary parts of the body structure and panelling were removed.

Fig. 1. Car body during the preparatory work

For the design basis adopted to be implemented in the final vehicle version, the car body had to be modified so as to increase its strength, to enable a wide range of adjustments of the vehicle running characteristics that may be affected by the car body shape and dimensions, to adapt the body for mounting the subassemblies having been prepared, and to minimize the vehicle mass [6, 13, 15, 17]. Therefore, the following operations were considered necessary during the designing process:

- to reinforce the pressure-welded joints between sheet-metal components of the car body by making additional welded joints;
- to close the unnecessary holes that may adversely affect the car bodywork strength;
- to make an enlarged central tunnel in the body floor and thus to enable the installation of a drive shaft if a need arises;
- to provide anchorage points for safety belts and driver's seat as well as for a fire extinguishing system and other systems to be installed in the car cabin in place of the factory-made passenger's seat;
- to modify the front MacPherson strut fastening points;
- to engineer and construct the rear MacPherson strut fastening points;
- to engineer and construct a bracket for the rear suspension subframe;
- to modify the factory-made inner wing panels;
- to modify the frame side members;
- to modify the rear part of the car floor in order to enable the mounting of RWD system components;
- to provide engine and gearbox assembly mounting points;

- to make and install a roll cage in accordance with FIA requirements;
- to apply lightweight body panelling components;
- to construct subframes;
- to provide adequate jacking points;
- to construct reinforcements and mounting brackets for vehicle subassemblies;
- to make additional modifications in order to facilitate vehicle maintenance and servicing;
- to provide mounting points for shields and guards for the mechanical parts and installations present in the car undercarriage.

Fig. 2. Roll cage, side part

Fig. 3. Car body prepared for the installation of subassemblies

4. Prime mover

As regards the selection of an engine to a specific vehicle in the categories where significant modifications are acceptable, the regulations of FIA and of all the subordinate organizations often include a very important clause, according to which the engine block and the vehicle body must be made by the same manufacturer [23]. This means that the choice of engines is strictly limited to those offered by the manufacturer of the specific car model. Thus, the engine selection depends on the selection of a car body or, in other words, the vehicle body may only be selected according to the engine chosen.

Based on the selected range of car bodies and engines, a specific engine model was chosen. According to one of the main assumptions of the design basis for the project, a 2-litre engine was to be used. Such an assumption was dictated by several factors other than the sole aim of making the maximum use of the vehicle class regulations. Firstly, the engines of this capacity even in their factory versions are characterized by significant rated power and torque. They show definitely greater potential in comparison with the 1.6 engines, which are equally popular in motorsports (the Clio S1600 engine has about 220 hp metric power rating and 240 Nm maximum torque as against about 200 hp metric power rating and 215 Nm maximum torque of the mass-produced 2.0 engine). The performance curve of such an engine is also much better because of higher torque even in the low range of engine speeds and more favourable shape of the torque curve. Additionally, the installation of an engine with a cubic capacity exceeding 2 litres is connected with a regulation requirement of raising the minimum vehicle mass. In an FWD car, the mass of the engine alone, which will obviously be greater in the case of a bigger engine, and the possibility of correct positioning of the engine in relation to the front vehicle axle are other factors of no small importance.

From among the 2 litre petrol engines offered by Renault, a pretty wide range generally denoted by "F4R" was chosen. The engines of this group are used in many motor vehicles of this brand. Their power ratings considerably vary depending on engine configuration. Such engines are also available in turbocharged versions, differing from each other in their auxiliaries, but having an identical cylinder block, which will make it possible to convert the vehicle to the SUPERCAR class. The best point of this block is the material it is made of, i.e. cast iron. Thanks to this, it is characterized by definitely higher resistance to the working loads in comparison with aluminium blocks [21]. The reasonability of such a solution is confirmed by some World Rally Cars (WRC), whose constructors provided them with cast iron engine blocks. The rightness of the decision of choosing an engine of the F4R group is also confirmed by the fact that such engines are used in the Formula Renault racing cars, where their service life is very long in spite of long distances travelled at extreme loads. The very easy availability of spare parts, both genuine and specially intended for modifying the engine performance characteristics, is also important from the vehicle operation and servicing point of view.

Following the selection of an appropriate engine, the engine was subjected to modifications. The modifications were made to components of the piston-crank mechanism, valve gear, induction and exhaust systems, and electronic control system. The modifications resulted in satisfactory effects; however, a safety margin was left to the values at which the engine failure rate might dramatically increase [8].

Fig. 4. Engine and gearbox assembly installed in the car body

A comparison between the prime movers of the base vehicle and the modified vehicle has been presented in Table 1.

Table 1. Comparison of motor vehicle tax in selected EU countries

Description	Base vehicle	Modified vehicle
Displacement	1 998 cm^3	1 998 cm^3
Type and configuration	Inline, naturally aspirated	Inline, naturally aspirated
Valvetrain layout	DOHC	DOHC
Number of valves	16	16
Valve timing type	Variable valve timing (VVT)	Variable valve timing (VVT)
Version	F4R 730	F4R 830 RS
Compression ratio	11:1	11.5:1
Stroke	93 mm	93 mm
Bore	82.7 mm	82.7 mm
Lube oil cooling system	Liquid-cooled	Liquid-cooled
Electronic control system	Siemens	ECUMaster
Exhaust manifold	4-1 header	4-2-1 header
Catalytic converter	Ceramic	Metallic
Maximum power	124 kW	183 kW
Maximum torque	199 Nm	245 Nm
Crankshaft speed at maximum power	6 250 rpm	7 400 rpm
Crankshaft speed at maximum torque	5 400 rpm	5 250 rpm
Maximum crankshaft speed	7 000 rpm	7 600 rpm

5. Power transmission system

The application of a high-performance sequential gearbox was given up until a decision is made as regards choosing the class in which the modified vehicle will be used. Among the gearboxes available in the market that can be coupled with the F4R engine block with no additional modifications, the one denoted by "TL4" seems to be the best one. It is a 6-speed synchromesh manual gearbox used in a few Renault motor vehicle models.

Its construction and materials are sturdy enough for cooperation with engines of high torque output. Its durability is confirmed by the fact that it is installed in factory-made sports versions of Renault cars. An alternative to the TL4 gearbox is a somewhat older model JC5, which is also used with the F4R engines of the highest performance characteristics. However, it is far more prone to failures. Its operation control method, which may be conducive to frequent defects, is another weak point of this solution, which precludes its trouble-free use in the conditions of competitions such as the rallycross.

Then, a decision was made to choose a combination of the TL4 gearbox housing with a set of gears developed specifically for the project and provided with dog clutches in place of synchronizers. Individual gear ratios and the constant mesh ratio were selected according to the engine performance curve [16, 20]. The clutch is operated by means of a hydraulic actuator; therefore, an additional clutch master cylinder with a fluid reservoir had to be installed at the pedal bracket. The gears are changed by means of a lever situated at the steering wheel. The gear change stroke of the lever was minimized to reduce the gear change time and, in consequence, the time during which only one driver's hand is in contact with the steering wheel [9, 10, 12].

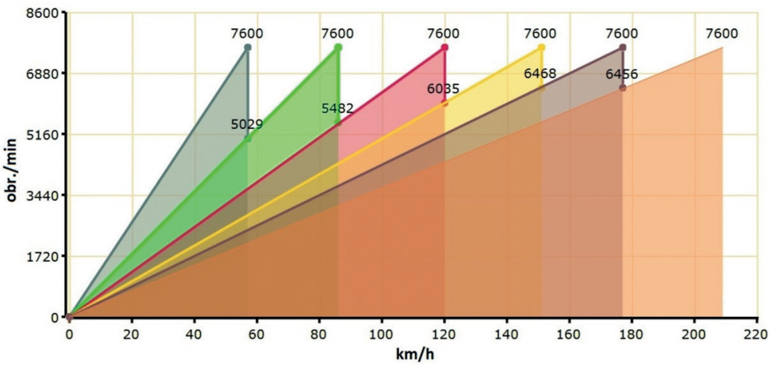

Fig. 1. Functional characteristics of individual gear ratios in the gearbox

The power transmission system was provided with a friction-type limited-slip differential (LSD). This enabled adjustability of important characteristics of the unit; thus, the unit may be customized to driver's preferences. The initial pressure is set by replacing the disc springs. Additionally, it may be precisely tuned by means of appropriate shims. The slip-limiting mechanism response characteristics may be adjusted by changing the ramp angles. The perfect setting of the LSD unit is laborious but it has a significant impact on the vehicle handling characteristics and, thus, on the sport result.

6. Suspension system

The engineering solutions applied to the base vehicle did not meet the requirements defined in the design basis for the modified vehicle [14]. Therefore, a decision was made to design and make a complete suspension system from scratch. Thanks to this, all the geometrical, kinematic, and functional characteristics of the system could be precisely brought to conformity with the requirements adopted.

Fig. 5. The rear point of fastening the MacPherson strut to the car body

Special stress was put on precise adaptability of the suspension system to current conditions such as road surface type, weather conditions, or particular properties of a specific section of the route. In consequence, all the suspension system characteristics are adjustable within a very wide range [1, 5, 22].

In sports competition conditions, the replacement of a complete suspension system with another one having radically different characteristics is often impracticable because of the time required for such an operation. Therefore, a suspension system was developed the construction of which made it possible to carry out necessary modifications or corrections within as short a time as possible and the components that sometimes must be replaced were designed in a modular form to reduce the time of the necessary servicing operations. This entailed a number of technological complications because most of the dimensional and kinematic characteristics of the system are closely connected with each other. A chief asset of the system having been developed is the practicability of quick minor corrections in case of a component failure or unavailability of a necessary spare part in the specific circumstances.

In motorsports, many situations may occur where suspension system components would undergo the action of a destructive force. Meanwhile, the measurable loss caused by a possible failure may significantly exceed the cost of the component to be replaced because this may result in a risk of failure to finish the race. This in turn may affect the sport result and, thus, thwart the entire investment, which may be thought as participation in the complete championship cycle. Therefore, all the suspension system components were so designed and made that, even if damaged to a significant extent, their failure should not prevent the race completion [19]. Thanks to this, the possible adverse impact of suspension system defects on vehicle performance in sports conditions was minimized.

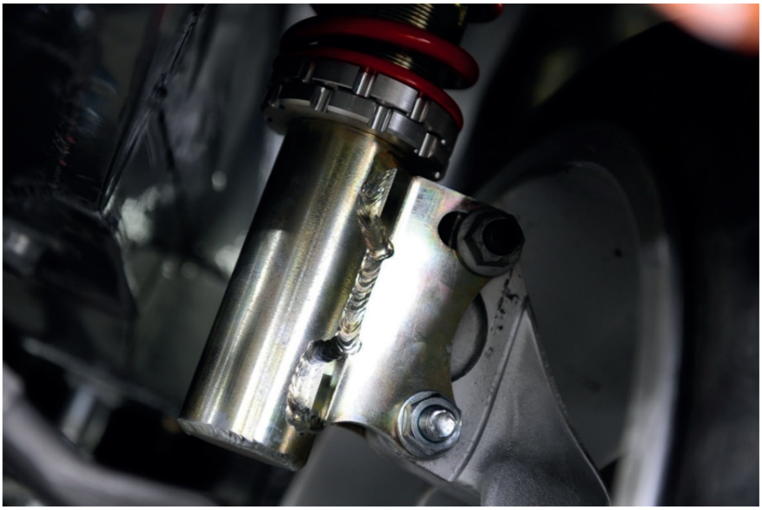

Fig. 6. A fragment of the MacPherson strut

7. Braking system

The modification of the braking system is aimed at improving its performance, which also means higher braking efficiency. This is particularly important for motorsports, because it allows delaying the start of slowing down the vehicle before a turn or an obstacle that must be evaded. The more efficient the braking system, the later the braking may be started and the shorter the braking distance is [2]. For the sport in which the modified car will be used, the applying of brakes before a turn as late as possible is an issue of critical importance, often decisive for the sport result.

The front wheels were provided with internally ventilated brake discs of 320 mm diameter [11]. The use of ventilation holes on the friction surfaces of the discs was given up because of a tendency for micro-cracks to appear around the holes due to abrupt temperature changes in result of e.g. contact with water. The gases released between the brake disc and the brake pad will be carried away by grooves milled on the friction surface. Another good point of the grooves is effective removal of the dust stirred up from the track surface.

In the base vehicle, the front-axle brake callipers have single pistons with a bigger diameter. For the modified car, a decision was made to use multiple-piston callipers with smaller piston diameter. Such a choice was made in consideration of the system of applying the piston force to the brake pad and, in consequence, to the brake disc. The multiple-piston calliper makes it possible to generate a greater braking force. Finally, four-piston general-purpose callipers made by a leading braking system manufacturer were chosen.

The rear axle was provided with solid brake discs of 265 mm diameter, with no ventilation holes or grooves, cooperating with two-piston callipers, with the piston diameter being bigger than that used in the base vehicle.

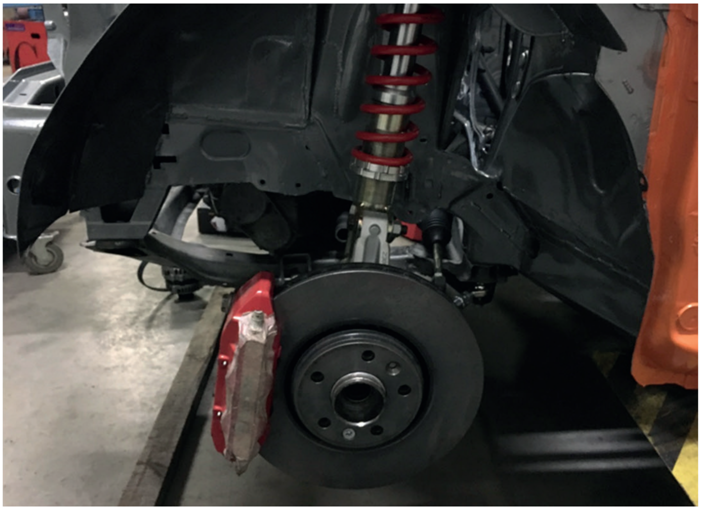

Fig. 7. Front wheel brake and suspension system

The method of operating the brake callipers was considerably altered, with the degree of controllability of the calliper operation being significantly extended in comparison with that being possible in the base vehicle. The vacuum brake booster was removed from the braking system because it disturbs the precision of controlling the brake fluid pressure in the system and, thus, detrimentally affects the vehicle controllability during sport drive. Therefore, the big single brake master cylinder was replaced with two smaller units, appropriately selected, and a special bracket for the new set of master cylinders was designed and made. Additionally, a braking force regulator was applied to correct the distribution of braking effort between the front and rear axle wheels.

The factory-made auxiliary brake system is not efficient enough for high-performance applications. In motorsports, it is required to lock up vehicle wheels provided with tyres of very high tyre-road adhesion and rotating with a high speed. Therefore, its efficiency had to be increased. An improvement in its performance was attained by replacing the mechanical auxiliary brake control system with a hydraulic one. The additional hydraulic system was incorporated in the service brake system. A special mechanism was built from scratch to operate two brake master cylinders with appropriately selected diameters by means of a lever situated close to the gear-change lever.

Major differences between the braking systems of the base vehicle and the modified vehicle have been presented in Table 2.

Tab. 2. Comparison between the braking systems

Description	Base vehicle	Modified vehicle
Brake disc diameter, front	280 mm	320 mm
Brake disc diameter, rear	238 mm	265 mm
Number of pistons in the front calliper	1	4
Number of pistons in the rear calliper	1	2
Calliper piston diameter, front	54 mm	40 mm
Calliper piston diameter, rear	30 mm	35 mm
Number of brake master cylinders	1	3
Auxiliary brake system	Mechanical	Hydraulic
Braking ratio regulation	Self-acting, within a narrow range	Manual, full-range

8. Recapitulation and conclusions

The recapitulation of the nearly eighteen-month work on the vehicle should be started from the table below. The table is a summary of the modifications carried out and presents the major differences between the base vehicle and the modified one. The actual performances of these two cars in sport drive conditions have not been compared yet; so far, they have not been measured either. However, the data given in the table below leave no doubt that the improvement in the performance of the modified vehicle may be considered significant.

Tab. 3. Comparison between the basic vehicle specifications

	Base vehicle	Modified vehicle
Prime mover		
Type and configuration	Inline, naturally aspirated	Inline, naturally aspirated
Displacement	1 998 cm^3	1 998 cm^3
Maximum power	124 kW	183 kW
Maximum torque	199 Nm	245 Nm
Gearbox		
Number of ratios	5 + 1	6 + 1
Maximum speed	220 km/h	209 km/h
Differential	Open	Limited-slip
Braking system		
Brake disc diameter, front	280 mm	320 mm
Brake disc diameter, rear	238 mm	265 mm
Number of pistons in the front calliper	1	4
Number of pistons in the rear calliper	1	2
Auxiliary brake system	Mechanical	Hydraulic

Tab. 3. Comparison between the basic vehicle specifications; cont.

	Base vehicle	Modified vehicle
Braking ratio regulation	Self-acting, within a narrow range	Manual, full-range
Suspension system		
Front	MacPherson struts	MacPherson struts
Rear	Torsion beam	MacPherson struts
Adjustment range	No considerable adjustment possible	Full-range adjustment of all characteristics
Body		
Overall length	3 773 mm	3 830 mm
Overall width	1 639 mm	1 830 mm
Total mass	1 065 kg	900 kg

As the final result of the work, the construction of a high-performance car to be used in professional rallycross racing has been engineered and such a car has been built. Simultaneously, the vehicle construction enables its quick and trouble-free adaptation for other motorsports.

The vehicle was built with making maximum use of subassemblies supplied by Polish manufacturers and all the prototype parts were made by Polish processing firms. Hence, it may be said that only a few subassemblies manufactured abroad were used to build the vehicle. The final market value of the vehicle cannot be estimated now because the vehicle has not passed yet the tests required and, in consequence, the "childhood diseases" that are quite likely in constructions of this type but may affect the total project cost could not be eliminated. Nevertheless, the economic objectives adopted for the project may be deemed as met.

The base car used for the alterations was a civilian version of the Renault Clio II model (of the second generation). As a target, the car was to be visually similar to the Clio S1600 model made by the Renault motorsport division). In visual terms, the two cars look almost identical; moreover, their technical characteristics are also very close to each other. In some aspects, however, the modified vehicle is definitely superior to the famous Clio S1600. All the modifications were made in full conformity with the FIA technical requirements. This will make it possible to obtain a good opinion from technical delegates of Polski Związek Motorowy – PZM (Polish Automobile and Motorcycle Federation) and to obtain a Sports Car's Logbook, which is the most important document for a motorcar used in motorsports.

Thanks to enlargement of the central tunnel in the body floor, modification of the boot floor, and construction from scratch of an independent rear axle suspension system enabling the adding of rear axle shafts, the car may be converted into rear-wheel drive (RWD) or all-wheel drive (AWD) versions. This has made it possible to enter the vehicle for races in various classes, which significantly extends the range of car usability. The 2-litre displacement of the engine used is an excellent compromise between mass and displacement for the SUPER NATIONAL class, in which the car will be tested. When provided with a turbocharger and modified as appropriate, the vehicle will also use to the full the provisions of the regulations for the SUPERCAR class. In the car versions prepared for both of these classes, the engine block will

Fig. 8. Finished vehicle officially presented at the Warsaw Moto Show 2017

Fig. 9. The car body has been significantly widened

be identical, thanks to which neither any change in the suspension system components nor any modification of the car bodywork will be needed.

The removal of unnecessary parts of the outfit of the factory-made car, replacement of steel panelling with parts made of composites, and use of light metal alloys considerably reduced the total vehicle mass. Furthermore, a very strong emphasis put on lowering the centre of vehicle mass will have a favourable effect on the vehicle handling and stability on road bends. The vehicle performance was not verified by measurements; therefore, it cannot be compared with that of the base car. Nevertheless, the numerical data indicate a significant improvement in comparison with the factory version of the Renault Clio II cars that can be met on roads.

The last of the factors that defined the direction of works was the facilitation of servicing the car. Every vehicle component, from individual parts to complete assemblies, was so designed, mounted, or used as to minimize the time needed for its adjustment, repair, or replacement. Thanks to this, possible defects can be quickly diagnosed and rectified. This is the best point of this construction. Thus, all the basic requirements adopted before starting the work have been met.

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