

The Porsche Carrera GT - an Innovative Vehicle Concept

by

Dipl. Ing. Michael Hölscher, Dipl.-Ing. Dieter Steinhauser
Dr. Ing. h.c. F. Porsche AG

Abstract

In the high-performance sportscar segment, the Porsche Carrera GT sets new standards in terms of driving dynamics and performances: Porsche decided to transfer pure racing technology to a road-going high-performance car which, at the same time, is ideally suited for everyday use and has excellent long-life characteristics.

This paper explains, how the engineering goals have been reached while bearing in mind the general requirements of automotive engineering. In addition, it presents the most important vehicle assemblies and highlights their integration into the overall vehicle concept.

1. Introduction

The new Porsche Carrera GT is a road-worthy high-performance car which has been fitted with all the attributes of genuine racing technology.

Its fascinating driving dynamics which include much more than just acceleration and top speed are setting completely new standards in this segment.

To achieve optimum performances - particularly in terms of directional stability, lateral acceleration and brake performance - special consideration has to be given to the weight, location of the center of gravity and overall stiffness. That is why, in designing the Carrera GT, all the relevant motorsport concepts have been made use of. The whole range of high-performance materials were utilized while, at the same time, consideration was given to customer-relevant criteria such as everyday

suitability, long-life characteristics, surface quality etc. This paper describes the overall concept of the Carrera GT and explains the special features of the main assemblies and their integration into the overall system.



Figure 1 Porsche Carrera GT

2. Complete vehicle

2.1 Engineering targets

The main target of race car engineering is to design cars which are able to yield high performance levels on race circuits. So, the most important requirements - which take priority over all the other engineering goals - are the following:

- Minimum weight
- Maximum stiffness
- Low moment of inertia about the vertical axis
- High aerodynamic downforce

- Lowest possible center of gravity

2.2 Vehicle concept

The Carrera GT is a two-seat roadster with a removable two-piece top. Unlike conventional car concepts, the Carrera GT is fitted with what is called a „rolling chassis“ - a design which is also frequently used in automotive racing. The rolling chassis consists of structural elements (that is the chassis and engine frame), mechanical units (that is the powertrain, suspension, cooling system etc.), and electrical components. It is fully operative even without the trim panels which have merely aerodynamic and esthetic functions and are without importance for the structural integrity of the rolling chassis. In motorsport, this design is chosen for its clear functional separation between the vehicle structure and the exterior panelling. It allows the inherent light-weight design potential to be made full use of and results in a vehicle structure of exceptional stiffness. A welcome side effect of this configuration is the possibility of rapidly replacing damaged body components during racing events.



Figure 2 Cutaway view of a rolling chassis

To further optimize the driving dynamics of the car the masses had to be concentrated near the center of gravity. This was achieved by choosing a mid-engine concept combined with a transversally installed transmission.

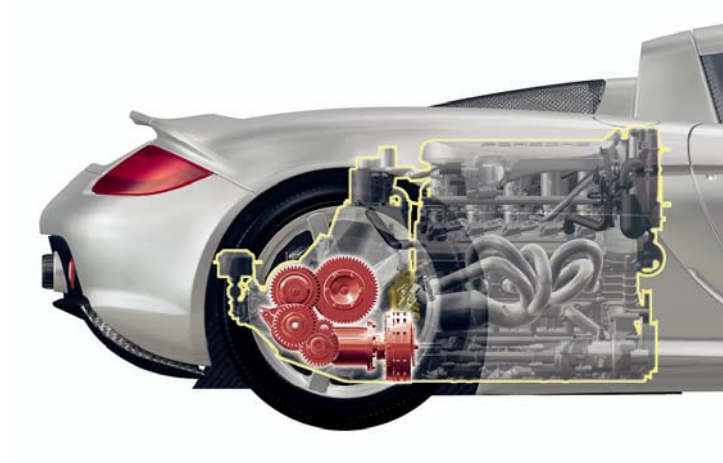


Bild 3 Mid-engine concept

This premise was kept in mind throughout the entire development phase. The 92 liter fuel tank, for example, is located at the center of gravity, too. Thus the fuel level does affect neither the wheel load distribution nor the handling characteristics of the car.

The demand for weight reduction was met by choosing light-weight materials wherever this was possible.

The most frequently used materials are the following:

- CFRP (Carbon-Fibre Reinforced Plastics)
- Aluminum
- Magnesium
- H400 high-grade steel
- Titanium

To obtain high aerodynamic downforces, a particularly efficient underbody geometry was developed which features diffusers, ventilation channels and spoilers. Further, the car is equipped with a hydraulically controlled pop-up rear wing which extends whenever a given speed threshold is exceeded. The downforce is further intensified by cooling-air supply and evacuation ducts at the front end of the car.



Figure 4 Underbody shield



Figure 5 Cooling air routing

3. Body

3.1 Structural components

The combined chassis (monocoque design) and engine frame of the Carrera GT could be called the backbone of the car.

This assembly has structural functions - such as, for example, the support of the wheel loads, of forces transmitted by the crash elements and of reaction forces generated by the drivetrain. And it also carries the exterior and interior parts and adjacent components.

This formal and functional combination is unique and, to date, has been used neither in motorsport nor in production cars. It includes numerous innovative concepts and components for which various patents have been issued.



Figure 6 Structural elements (chassis, supporting structure)

Making use of the inherent advantages of the Rolling Chassis, it is possible to very precisely study and further improve the main functions of the structural components.

The manifold functional demands for example for the monocoque result in complex loads which must be compensated by specifically optimizing the geometries and materials.

Doubtlessly, the bending stiffness of an open car strongly depends on the configuration of the entrance area. This is an example for the load dependent use unidirectional reinforcing fibres.

It is not possible to increase the sill dimensions just as the engineer likes in order to improve the bending stiffness. Also the ease of entry and exit has to be kept in mind - a demand which is of equally great importance for a car of this category. Some freedom of design, however, is offered in the transition areas between the A and B pillars. And unidirectional fibres oriented in the main direction of tension are ideally suited to achieve extraordinarily high stiffness levels without resulting in any significant weight increases.



Figure 7 Chassis, orientation of unidirectional fibres (red)

Within the scope of the Carrera GT development, the following rear-end concepts were investigated as a support structure or the drive train:

- Conventional steel frame
- Aluminum Space Frame
- Integral CFRP components

The main advantage of the conventional approaches was the enormous engineering know-how gathered during a multitude of previous applications. Very quickly it turned out that compromises would have to be made between the stiffness and weight demands and that package restraints would lead to insufficient solutions. The entirely new “supporting structure” (see Figure 6) made of CFRP allowed significant progress to be made in terms of car weight and stiffness. Comprehensive mathematical analyses and optimizations were carried out taking into account the loads occurring during car operation and collisions.

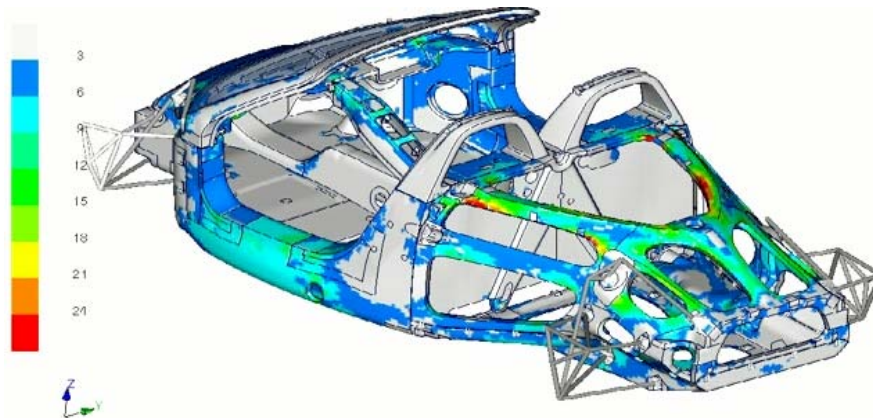


Figure 8 Stress patterns during the One Wheel Drop test (simulation)

The highly integrated structure created for the Carrera GT stands out not only for its extraordinary stiffness - which equals that of competitive motorsport cars - but also for its extremely low weight.

Thanks to the design freedom offered by this particular technology, the requirements of the individual assemblies could be fully allowed for without impairing the overall performances of the car.

3.2 Exterior

With the exception of the front and rear bumpers and several small-size parts, all the exterior components including the doors, lid, hood, and roof shells are made of fibre composite material.

In some cases, highly integrated partitioning concepts were adopted from the motorsport domain in order to reduce weight: the front panelling for example includes the fenders and luggage-compartment dish. For all the components relevant for joints and gaps (exterior/interior/structural elements) the Porsche reference point system (RPS) was consistently applied.

For weight reasons, at the exterior panels sandwich structures are used in exceptional cases only. Generally, the components are of monolithic design, i.e. depending on the respective demands, a component consists of several layers of carbon-fibre material with an overall wall thickness of approx. 1.2 mm. The welcome side effect of this configuration is an improved crashworthiness.

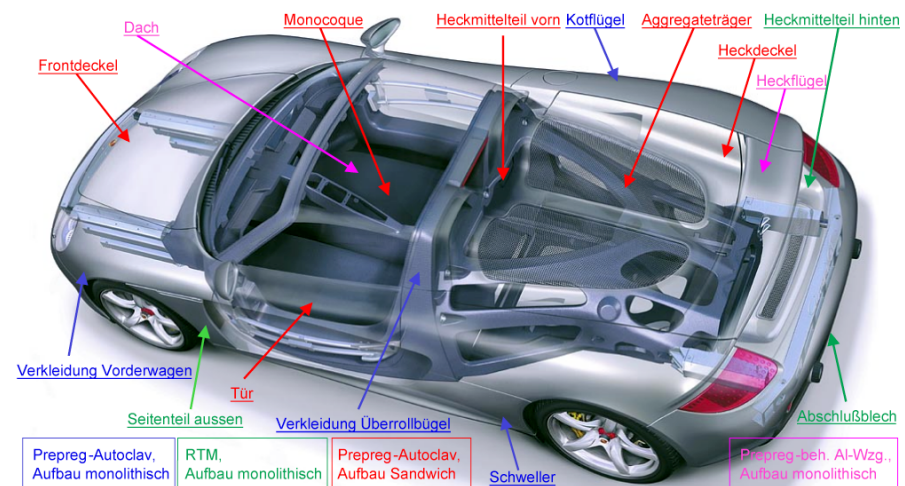


Bild 9 Exterior CFRP components

Development targets known from conventional body engineering - such as the optimization of buckling resistance for example - can have low priority only because of the particular material properties of the fibre composites used.

To date, exterior components made of CFRP have been known for their esthetically poor surface quality. The effects of conventional smoothing procedures - such as the application of fillers and additional polishing - are mostly short-lived. If no appropriate countermeasures are taken, irreversible fabric reliefs („golf ball effect”) start appearing soon under the influence of temperature, humidity and light. Those are quality defects which Porsche cannot accept.

By systematically investigating most different material configurations, a multi-layer surface has been developed (and patented) which outdoes conventional surfaces as it remains stable over a temperature range which goes far beyond 90°C. Usually, any visible traces of the embedded fabric disappear again after the material has cooled down.

3.3 Interior

Unlike a race car whose interior, above all, has to be functional, the interior styling of the Carrera GT must also reflect the exceptional character of this automobile.



Bild 10 Carrera GT interior

Of course, while giving consideration to esthetic aspects, the weight targets mentioned in the beginning must never be forgotten. That is why the advantages of the fibre composite materials are also made use of in the interior: passive safety, for example, is enhanced by the instrument panel made of aramide fibres.

The car is fitted with newly designed carbon-fibre seats which comply with all safety regulations worldwide.

The series version of this seat, complete with upholstery, leather trim and all fittings, weighs just 10.3 kg.

The center console consists of deep-drawn galvanized magnesium. This metallic light-weight component impresses with its high optical and haptic quality.

3.4 Safety

Compliance with Porsche's safety standards had to be taken into account in the early concept phase already as light-weight design and performance must never impair automotive safety.

The restraint system consists of driver, front-passenger and side airbags, three-point safety belts with belt tensioners and belt-force limiters and knee impact bolsters. When developing the interior components and selecting the material systems attention was paid to minimize the injury risk during impacts.

Based on the experience gathered in motorsport the Carrera GT was provided with a stiff survival cell (monocoque design) which means that the load-bearing elements of the chassis with rollover protection integrated in the A and B pillars and the supporting structure are in compliance with the worldwide safety regulations and do not suffer any structural damages when tested in accordance with the relevant safety regulations. Most of the energy is absorbed by the crash structures made of austenitic high-grade H400 steel which also serve as supporting elements for such devices as radiators and cooling-air ducts.

The centrally located fuel tank is optimally protected by the surrounding structural CFRP panels.

Parallel to the development of the safety-relevant components and configurations, comprehensive FE simulations of the worldwide crash tests were carried out and to reach a clear understanding of the overall system corresponding basic investigations had to be performed.

The most essential development phases were the following:

- Selection of suitable simulation tools
- Detailed FE-modelling of material structures
- Determination of the required itemization level
- Systematic investigation of material laws and failure mechanisms of real-life material structures.
- Investigation of the interactions between monolithic and sandwich materials in combination with metallic materials (crash structures, radiators, hydraulic components etc.)
- Systematic comparison of the results of simulations and tests

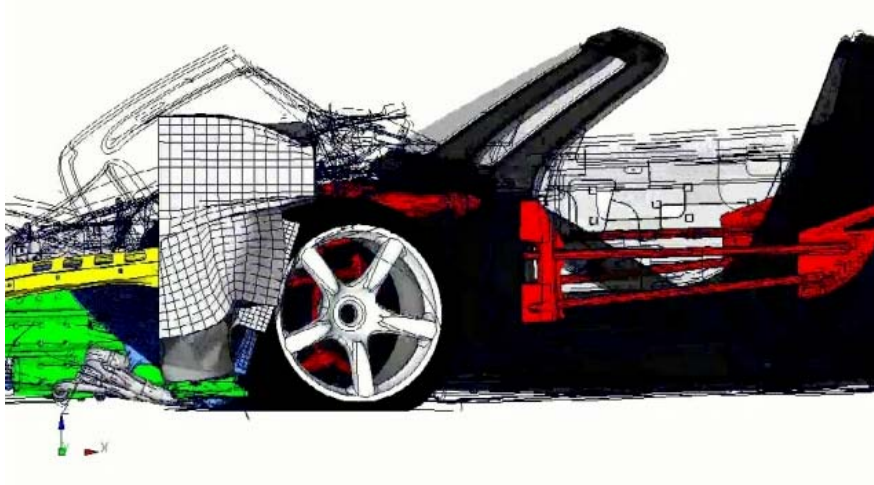


Figure 11 Simulation of a frontal crash

4. Chassis

As in motorsport, the chassis specifications requested superior handling on both dry and wet road surfaces as well as utmost braking performance.

The front axle is a double-wishbone design with forged aluminum wishbones which are rigidly connected to the chassis via steel ball joints. As in race car design, the normal forces are transferred to the horizontally arranged spring struts via pushrods and needle-bearing-supported rocker arms.

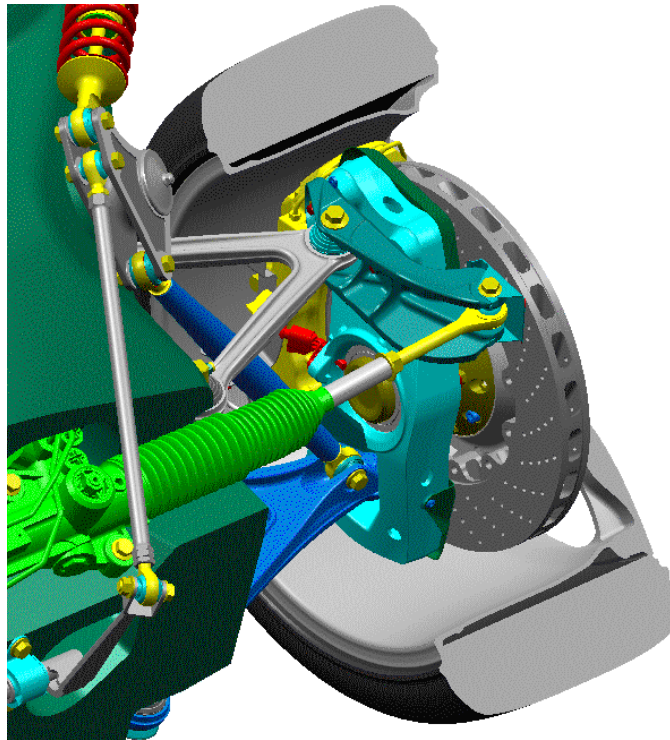


Figure 12 Front axle

The rear axle shows the same conceptual features as the front axle. The lower wishbone consists of welded H400 steel and is somewhat longer. The aerodynamic wishbone profile is obtained by internal high-pressure metal forming. It is arranged in the diffuser air flow.

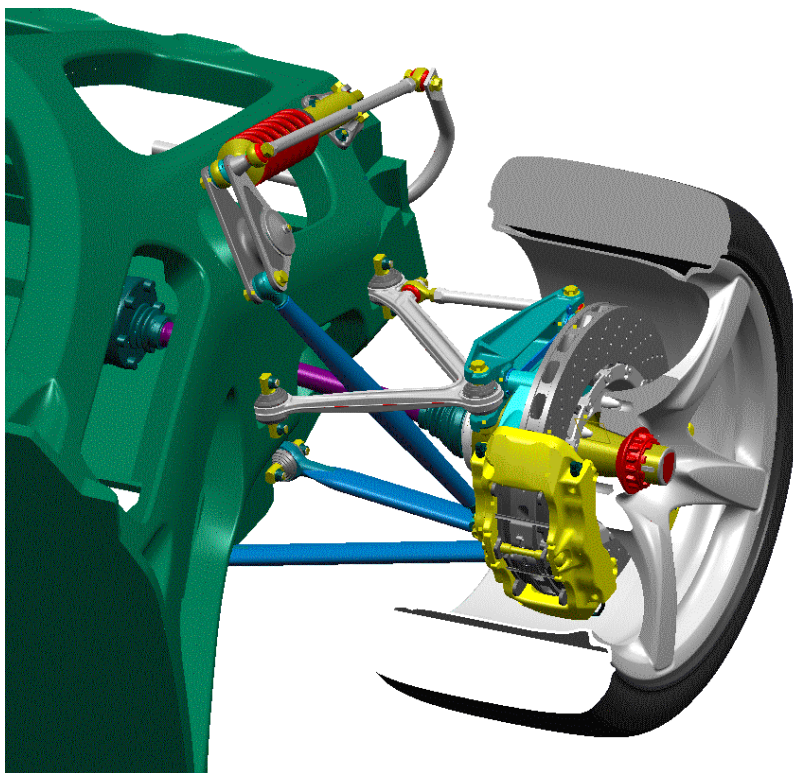


Figure 13 Rear axle

For the first time, the forged magnesium rims (front: 9.5Jx19; rear: 12.5Jx20) have been combined with tires (front: 265/35ZR, rear: 335/30ZR) featuring a 2-component running surface which has an optimized outer shoulder for high side-force transfer and an equally optimized inner shoulder for good wet behaviour and which allows a sufficiently high mileage to be reached. Both, the front and rear wheels are fitted with Porsche developed central-locking hubs.

As with all Porsche cars, the brake systems of the Carrera GT, too, has been designed set new standards.

The extremely light and wear-resistant 380 mm-diameter ceramic brake disks (PCCB) with especially developed 6-piston brake calipers mark the latest technological achievement for roadgoing cars.

5. Drivetrain

5.1 Engine

The engine of the Carrera GT is a direct descendant of the 10-cylinder race engine developed for LeMans 2000 which only has been modified to comply with the worldwide emission and noise regulations to be met by road-going cars. Of course, the engine was tuned for everyday suitability, driveability and durability without sacrificing, of course, such typical motorsport characteristics as spontaneous power development, excellent engine dynamics and a fascinating sound.

The nominal power of 450 kW (612 HP), torque of more than 400 Nm already at 1,500 rpm, maximum torque of 590 Nm and cutoff speed of 8,400 rpm are just a foretaste of the real power output and fascination of this engine.

In a race car, the crankcase with integrated bearing pedestals and a closed-deck dry-sump oil pan is used as a supporting element. As compared with the motorsport version, the bore diameter was increased by 2 mm to 98 mm to obtain a displacement of 5,733 cm³. The engine block was increased by 7 mm in order to provide space for the installation of an additional piston ring.

The lower crankcase half is just 98.5 mm high and - combined with a suitable small-diameter clutch - can be installed extremely low in the car.



Figure 14 Engine

The engine features a sophisticated crankcase-integrated lubrication system fitted with 10 oil pumps, i.e. 1 pressure pump and 9 evacuation pumps to allow oil evacuation of the individual crank chambers as well as the cylinder heads and the timing chain case.

The oil tank is integrated into the transmission housing which has cast-in oil ducts. A cyclone separator serves as a foam suppressor before the oil is fed back into the fresh-oil circuit via an oil-to-water heat exchanger.

The lubricating system has been laid out for lateral accelerations of up to 2.5 g to ensure safe engine operation also under motorsport conditions.



Figure 15 Crankcase upper/lower halves

High rpm stability and outstanding dynamics number among the most vital features of a racing engine. Forged titanium conrods and light-weight slipper pistons help to reduce the inertia forces while the low-weight crankshaft with its low moment of inertia and combined with a small diameter multiplate clutch ensure a spontaneous dynamic engine response.



Figure 16 Crankgear

5.2 Clutch

As has been explained above, a low center gravity is very important for the competitiveness of a car. The engine of the Carrera GT in combination with a multidisc clutch adopted from motorsport is ideally suited for a particularly low installation.

The clutch disks are made of industrial ceramics similar to those used for the brake disks. This allows the required performance density to be realized without impairing the durability

The 169-mm-diameter Porsche Ceramic Composite Clutch (PCCC) allows a maximum torque of 1000 Nm to be continuously transmitted.

The clutch of the Carrera GT weighs just 3.5 kg which is one third only of the mass of the 911 Turbo clutch. And due to the low clutch diameter the mass moment of inertia accounts for one tenth only. These exceptionally good results are due among others to the utilization of titanium for the supporting plates of the clutch friction pads and the central clutch driver element.



Figure 17 Porsche Ceramic Composite Clutch (PCCC)

5.3 Transmission

The extremely severe requirements with regard to the overall concept of the car excluded the installation of a standard transmission. In order to cope with the specific boundary conditions in terms of input torque, wheelbase, aerodynamics and center-of-gravity level, a completely new transmission was developed for the Carrera GT.

It was decided to use a transverse transmission with integrated engine oil tank and cyclone separator for oil foam suppression. With this concept, the masses are

concentrated at the center of gravity while providing space enough for the installation of a aerodynamic diffuser across the entire width of the car.

Unlike conventional drivetrains, the function of the 2-mass flywheel is taken on by the transmission. The input shaft with its particularly adapted torsional stiffness and the bevel gear represent the spring/mass system which filters the vibrations excited by the engine and largely eliminates the rattling noises produced by the transmission.

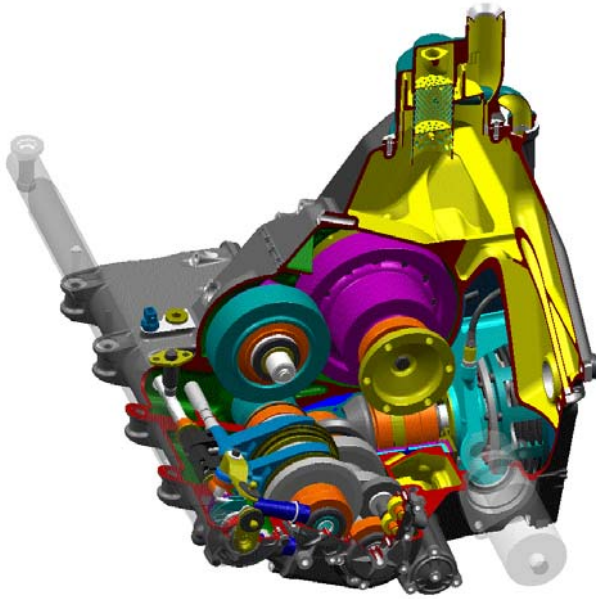


Figure 18 *Transverse transmission with integrated engine oil tank*

All these measures combined - that is the light-weight crankgear, PCCC and the elimination of the 2-mass flywheel – significantly lower the rotating masses and therefore they lead to a considerable reduction of the moments of inertia. The resulting engine excels by an exceptionally good response and aggressive revving-up capacity - features which are usually found only in race cars of the top-performance category.

6. Conclusion

The Carrera GT features a multitude of innovative technologies which are new in both, production and motorsport cars. Its true fascination, however, is revealed at the steering wheel - either on a race track for drivers with motorsport ambitions, where its dynamic response and agility bear witness to its real genetic heritage - and also, of course, on normal roads where it provides evidence of its versatility, whether on high-speed autobahn sections, on Alpine passes or along picturesque coastal roads...

7. Technical data and performances

Dimensions

Length:	4613 mm
Width:	1921 mm
Height:	1166 mm
Wheelbase:	2730 mm
Ground clearance:	86 mm
Turning circle:	12.9 m
Trunk volume.:	76 l
Fuel tank volume:	92 l (refuelling)
Curb weight (DIN):	1380 kg

Driving performances

0-100 km/h acceleration:	3.9 s
0-160 km/h acceleration:	6.9 s

0-200 km/h acceleration:	9.9 s
Top speed:	330 km/h

Body

Body-in-white:	Chassis and engine frame made of high-stiffness CFR honeycomb sandwich material; structural connections by means of integrated aluminum components
Crash structures:	Energy-absorbing high-grade steel (H400) profiles with precisely defined deformation characteristics
Bumpers:	Aluminum cross-member; PUR panellings; integrated cooling-air inlet frames
Panellings:	Weight-optimized CFRP components
Doors:	Weight-optimized CFRP components with honeycomb reinforcements; integrated side-impact protection elements made of high-strength steel tubes
Lids, front/rear:	Weight/stiffness-optimized CFRP components with honeycomb reinforcements; optimized crash behaviour
Roof:	Two high-strength light-weight shells made of CFR honeycomb sandwich material; quick-connect fasteners complete with locking devices
Rear wing:	Made of weight/stiffness-optimized CFR honeycomb sandwich material; speed/load-dependent hydraulic pop-up control
Glazing:	Windshield made of tinted laminated safety glass with integrated antenna; side windows made of tinted single-layer safety glass; three-piece rear window; side elements made of PC, center element made of laminated safety glass, antiglare treatment
Interior:	Supporting elements made of reinforced aramide-fibre composite material, leather-lined; instrument panel trim in titanium colour; door panels with carbon trim; center console made of deep-drawn, coated magnesium sheet metal; structural elements with carbon trim; light-weight seats made of CFRP -aramide composite material, leather-lined, manually adjustable

Air conditioning: AC with an externally controlled compressor

Fuel tank: Made of plasmatron-welded aluminum deep-drawn sheet metal; tank ventilation via a charcoal canister (worldwide); fuel supply system fully operable at lateral accelerations of up to 1.7 g

Safety: Driver, front-passenger, and side airbags; three-point safety belts with belt tensioners and belt-force limiters; knee-impact bolster; aramide-fibre-reinforced interior components; safety cell with integrated rollover protection; energy-absorbing front/rear-end structures; integrated side-impact protection in the doors

Electrics

Equipment: Central locking system; power windows, electrically controlled and heated outer rear-view mirrors; electrically controlled lid/hood release systems; immobilizer; alarm system, RDK

Audio system: Porsche Online Pro radio with integrated BOSE sound system, radio and CD-Player; cell phone; navigation system

Lighting equipment: Projection-type Bi-Xenon-module main headlamps with additional projection-type halogen driving lamps; rear LED lights

Chassis

Front axle: Double-wishbones with pushrod links

Rear axle: Double-wishbones with pushrod links

Rims (front/rear): 9.5x19 ET6 / 12.5x20 ET44 with center wheel nuts

Tires (front/rear): 265/35 ZR19 / 335/30 ZR20; RDK

Brakes: disc brakes with ceramic rotors (PCCB) Ø380 mm, 6-piston aluminum calipers

Driving stabilization: Traction Control with ASR, mech. locking differential

Engine

Number of cylinders:	V 10
V-angle:	68°
Valves per cylinder:	4
Valve control:	2 OHC, rigid bucket tappets, continuous intake camshaft phasing; combined gear/chain drive
Bore/stroke:	98 mm / 76 mm
Displacement:	5733 cm ³
Max. power output:	450 kW (612 PS) at 8000 rpm
Max. torque:	590 Nm at 5750 rpm
Compression ratio:	12.0:1
Pollutant category:	EU 4/LEV
Oil supply system:	Dry-sump lubrication, separate oil tank with cyclone separator integrated in the transmission housing; 9 evacuation pumps; 1 pressure pump

Power transmission system

Manual transmission:	6-speed
Clutch:	Dry double-disk ceramic clutch (PCCC)