AUTOMOBILE DIVISION

THE DEVELOPMENT OF THE PORSCHE TYPE 917 CAR

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For approximately twenty years Porsche has participated in motor racing. The development of Porsche production cars takes advantage of a major part of the experience accumulated during these performance-oriented activities.

This paper deals with the development of the Porsche 917 racing car which is powered by an air-cooled 12-cylinder engine producing about 630 DIN hp. The application of lightweight materials like titanium, aluminium, magnesium, fibreglass, etc. is also described.

The Porsche 917 racing car which obtained its Fédération Internationale de l'Automobile homologation by a series of 25 in April 1969 has now become the most successful car in motor racing throughout the world. In 1970 the 917 car was the overall winner at the 24 hours race at Le Mans.

1 INTRODUCTION

In 1968 Porsche decided to develop a sports racing car incorporating a 4·5 litre (274 in^3) 12-cylinder engine. At that time regulations only permitted the prototype sports car up to 3 litre (183 in^3) or so-called 'series sports cars' up to 5 litre (305 in^3) as a maximum. Prototypes were not subject to weight limits nor production figures. The 5 litre sports cars, however, required a minimum weight of 800 kg, exclusive of petrol, and a minimum production of 25 cars.

When the 917 project became known experts said that an air-cooled engine of this size was not feasible, but the development of the 917 proved the critics to be wrong.

In 1969 Porsche demonstrated twenty-five 917 sports racing cars to the international committee of the Fédération Internationale de l'Automobile (F.I.A.). Thus the 917 was approved and admitted to world championship racing events after ten months of development, construction and testing.

We now know that the cooling properties of the 917 12-cylinder engine are superior to all of Porsche's earlier air-cooled racing engines. This holds for the engine temperatures as well as for the power requirements of the cooling air blower drive. For instance, the power required by the blower of a 3 litre 8-cylinder engine was 14 hp at an engine performance of 360 hp, i.e. 3·9 per cent, while the power requirement for the 917 is only 17 hp, i.e. only 2·7 per cent of the engine performance of approximately 630 DIN hp.

Apart from the favourable effects on publicity, Porsche has always regarded its construction of racing cars and its participation in racing events to form a major part of its advanced development for production cars. For example, racing car experience has enabled Porsche to use lightweight magnesium material in their production of type 911.

Fig. 1 shows parts of the engine and gearbox for the 911 production car. All parts shown (except the cylinders) are of die-cast magnesium.

Twenty years of experience in the construction of performance cars preceded the 917 development. Fig. 2 shows the performance ratings for Porsche production and racing engines for the years 1960–70. There has been a remarkable increase in the performance of racing cars during the last 5 years; during this period the engine performance increased from 210 to 630 hp.

2 ENGINE

Fig. 3*a* shows the air-cooled 12-cylinder 917 engine with two overhead camshafts for each bank of cylinders. The engine has two valves per cylinder, twin ignition, i.e. two plugs per cylinder, and fuel injection.

The original 4·5 litre (274 in^3) version had a 85 mm bore with a 66 mm stroke and the engine developed approximately 565 DIN hp at 8400 rev/min. A 4·9 litre (300 in^3) engine was used for the first time in the world championship race at Monza in 1970. This version had a 86 mm bore and a 70·4 mm stroke which produced 600 DIN hp at 8300 rev/min. A 5 litre version with a 86·8 mm bore and a 70·4 mm stroke developed about 630 hp and was used in the 1971 Brands Hatch race for the first time.

Fig. 3*a* shows, in the foreground, the Bosch 12-plunger injector pump which was specially developed for this engine. It is driven via a tooth belt by the left-hand inlet side camshaft. The cooling blower is placed horizontally above the engine and is made from fibreglass-reinforced plastic. The induction tubes, the tube covers and the entire air ducting are made from the same material. The two twin-circuit distributors are visible in front of the blower and behind it.

All cast engine parts with the exception of the cylinder

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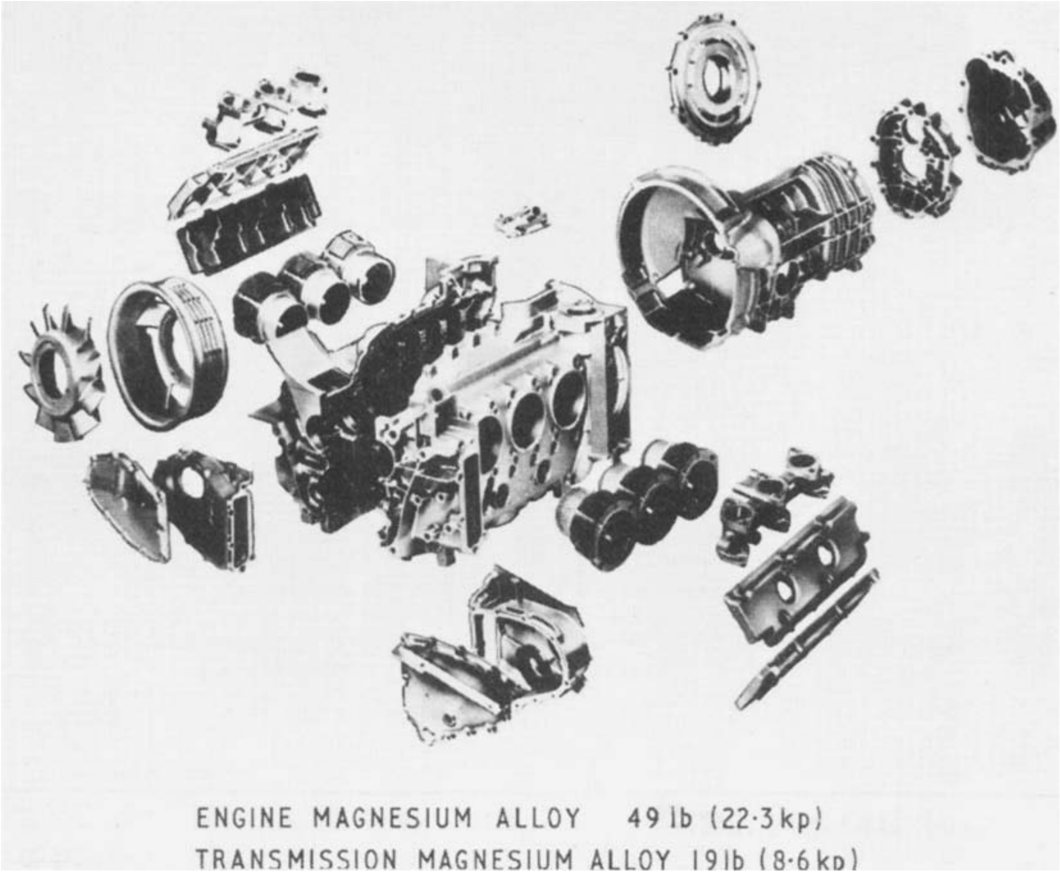

Fig. 1. Die castings of the Porsche 911

heads are made from RZ 5, a magnesium alloy to the United States specification ZE 41 A. This alloy has a high heat resistance, a good tensile strength and a homogeneous structure; furthermore the castings are resistant to pressure, even at small wall widths. The casting properties of RZ 5 are excellent. This magnesium alloy is only suitable for sand casting; but this is not important as castings for racing cars are generally cast in sand moulds in view of the relatively small number of parts involved.

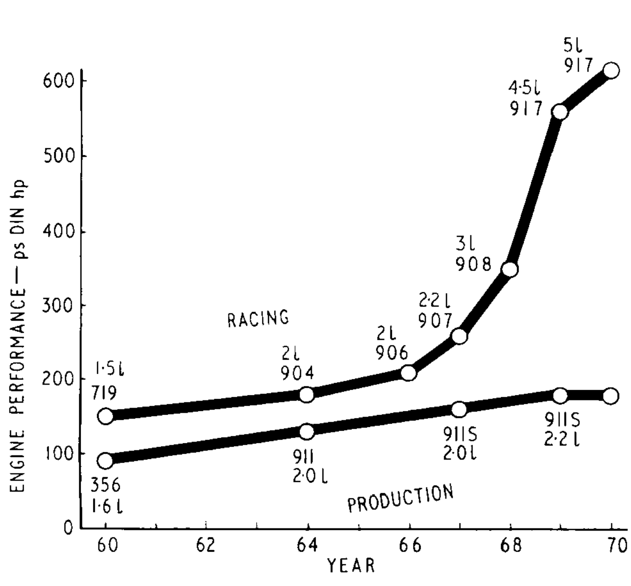

Fig. 2. Performance curves, Porsche engines

The weight of the complete 917 engine is 240 kg (528 lb). Total weight of all magnesium alloy parts is 70·7 kg (156 lb), i.e. 29·5 per cent of the total engine weight.

Fig. 4 shows the crankshaft of the 12-cylinder engine. The most spectacular design feature of this engine is its central drive. The engine power is taken via a pinion located at the centre of the crankshaft and is transmitted to the gearbox via a layshaft.

Every engine designer is aware of the difficulties caused by the natural vibration of the crankshaft which affects the moments created at the flywheel or the camshaft drive. All of these difficulties which are known to grow with the size of the engine—respectively with the length of the crankshaft—were avoided by using the central drive on the 917 engine.

Fig. 4 shows the shape of the natural vibration of the crankshaft which is 794 mm (31·3 in) long. At the centre of the shaft is a vibration node. This ensures that no torsional vibrations will occur at the central drive pinion. The four camshafts, the ignition distributors and the cooling blower are driven by this centre pinion. There are no overlapping vibrations and this is a major advantage, particularly for the valve gear drive.

There is no doubt that the more complex design of the central drive of the 917 engine has been worth while. Almost no mechanical problems were encountered during development of the different drives, and this is mainly due to the central drive design concept.

Fig. 5 shows a longitudinal section of the 917 engine; a photograph of the assembled right crankcase-half is also

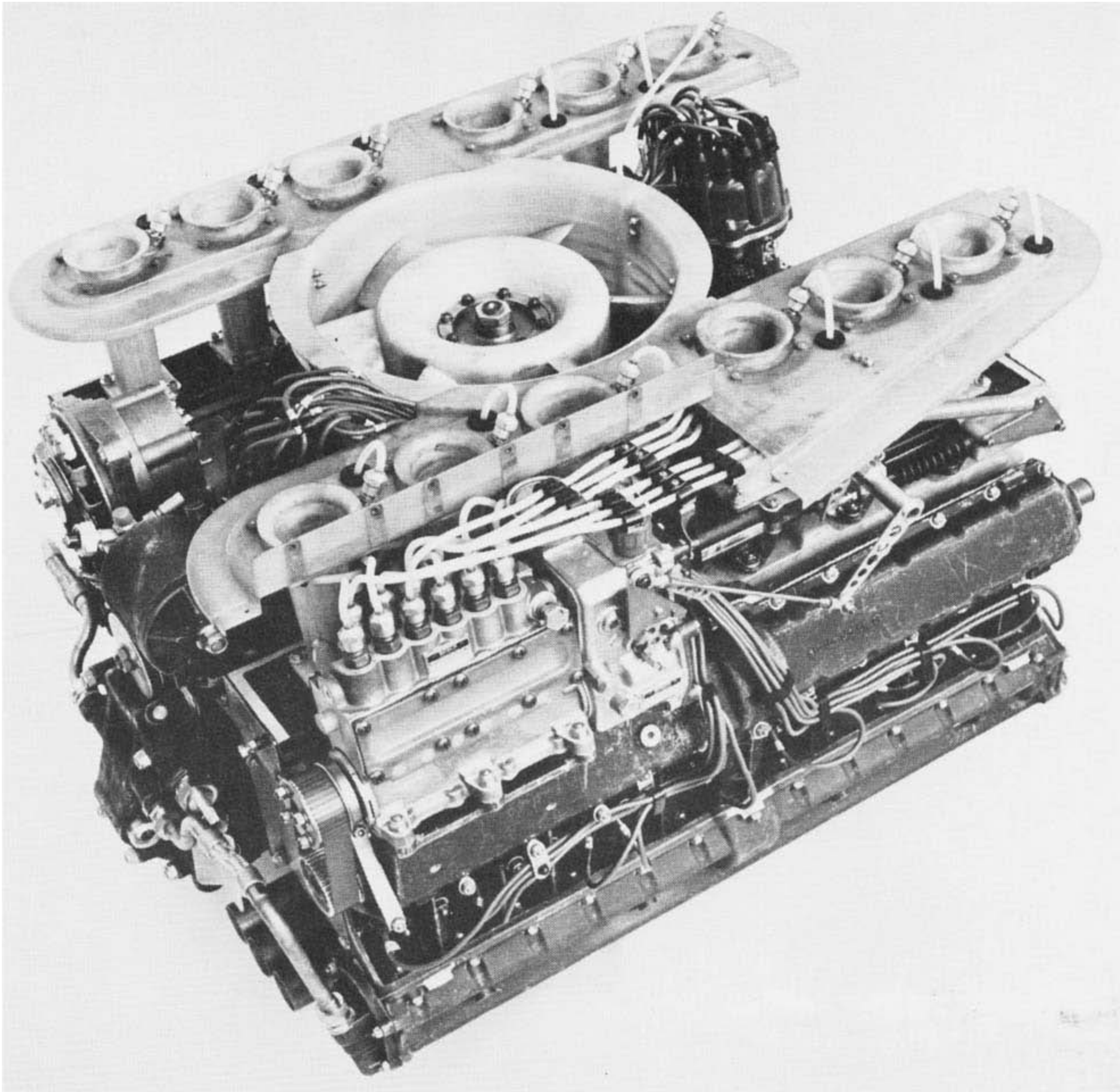

Fig. 3a. Porsche 12-cylinder 917 racing engine

shown for comparison. The power transmitting drive is easily recognized. The centre crankshaft pinion with its 32 teeth transmits the power via the lower pinion having 31 teeth, and the layshaft which is 22 mm (0·866 in) in diameter, to the clutch and gearbox. The layshaft acts like a torsional spring and will thus compensate for heavy shocks in the power transmission.

A titanium shaft of 24 mm (0·945 in) diameter to replace the steel layshaft was in the meantime successfully tested. The weight of the titanium shaft is 1·020 kg (2·25 lb) compared to the 1·585 kg (3·49 lb) of the steel shaft, a weight saving in this case of 0·565 kg (1·24 lb).

During the past few years titanium—we mainly use the alloy Ti Al 6 V 4—has become an everyday term in our racing car development. The strength and weight of titanium, compared with that of steel is far superior. For instance, the titanium alloy Ti Al 6 V 4 attains 110 kp/mm^2 (155 000 lb/in^2) which is the strength of first-class steel, but at only 57 per cent of the steel weight. However, there are a few applications requiring certain properties which are fulfilled by steel and not by titanium.

In compliance with the teeth relationship of 32:31 of the two pinions, the layshaft and clutch work at higher rev/min than the engine. The 1:1 relation was deliberately avoided as the matching of the same pair of teeth during every rotation is known to affect life endurance of a pinion gear.

As shown in Fig. 5, the main oil pump is located in the front crankcase and is divided into two scavenging chambers for the front and rear crankcase part and the actual pressure pump. The drive is effected via a pinion screwed to the front end of the layshaft.

Another layshaft drives the two ignition distributors and the alternator, and via two bevel gears the cooling blower is located above the crankshaft and is driven by the centre pinion.

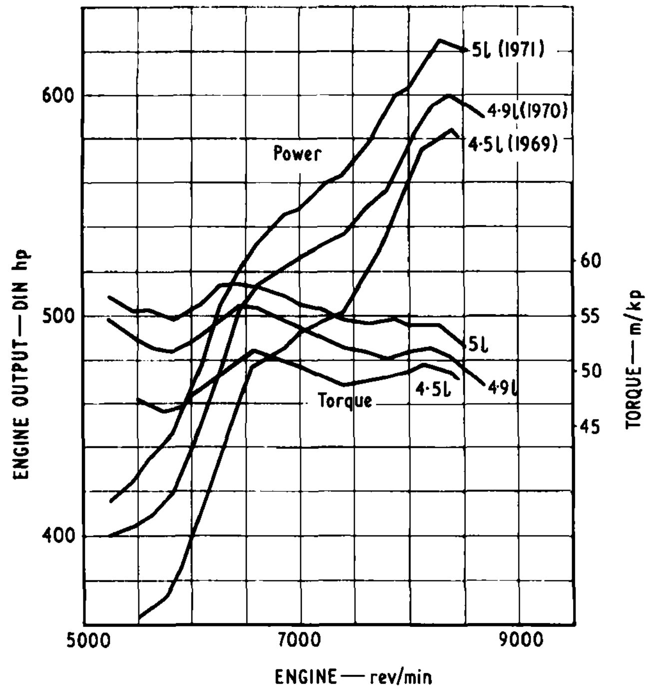

Fig. 3b. Output and torque of 917 engine

Fig. 6 shows a cross section of the 917 engine. The right half of the figure shows a centre section of the engine, i.e. at the central drive, and the position of the gear-wheels for the camshaft drives. The five pinion wheels between the crankshaft and the camshafts are located in one housing and mounted on pin bearings. An experimental engine combining, in its valve gear drive, steel, titanium and aluminium pinions was successfully tested.

The left half of the figure shows, among other things, the position of the front ignition distributor and its drive via the layshaft. The rear ignition distributor is positioned symmetrically in the right half of the crankcase.

Also shown in the left half of the figure are valve positions. The intake and exhaust valves are trepanned and have a sodium filling. The head of the intake valve has a diameter of 47·5 mm (1·87 in), compared to 40·5 mm (1·595 in) at the exhaust valve. The valve lift of the intake valve is 12·1 mm (0·477 in), that of the exhaust valve is 10·5 mm (0·413 in). Maximum valve acceleration is 0·0134 mm (0·000 528 in)/sq. degree cam angle; maximum deceleration is 0·0056 mm (0·000 220 in)/sq. degree. The intake valve is positioned at an angle of 30° to the cylinder axis and the exhaust valve at an angle of 35°.

The valves are actuated via cup-shaped cam followers. In our experience, the valve gear of the 917 engine could almost be called an optimum solution: a vibration-free drive from the crankshaft, a rigid power transmission via pinions and no flexibility in the valve actuation gear due to the cup-shaped cam followers.

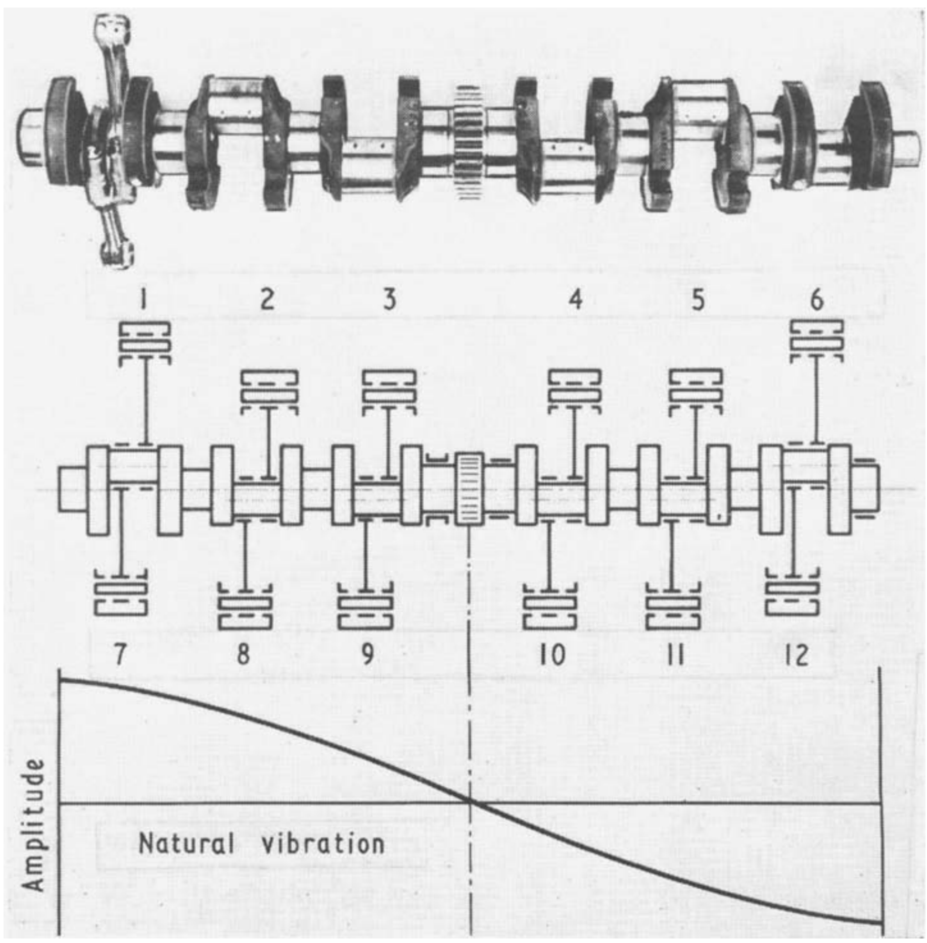

Fig. 4. Crankshaft of the 917 racing engine

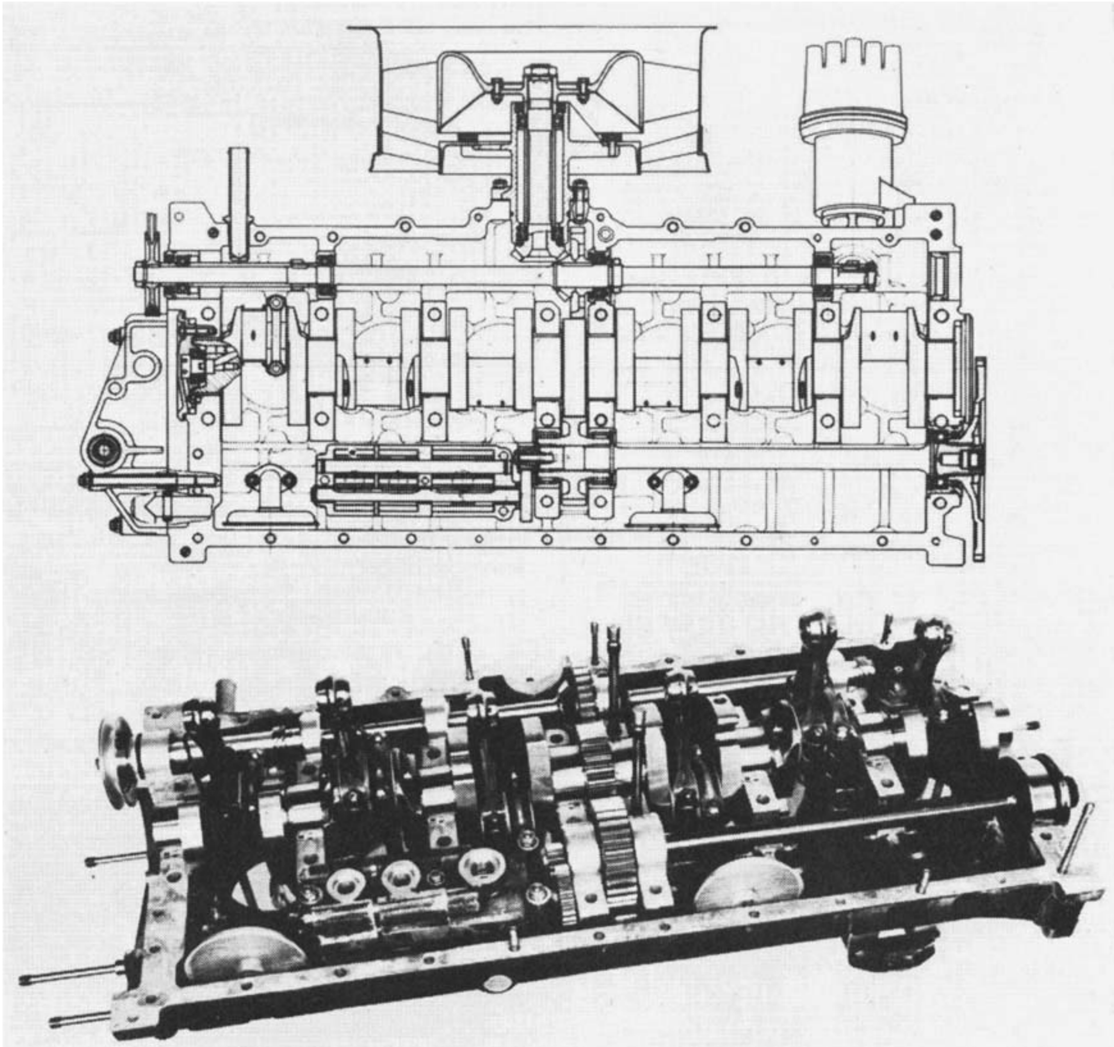

Fig. 5. Longitudinal section of the 917 racing engine

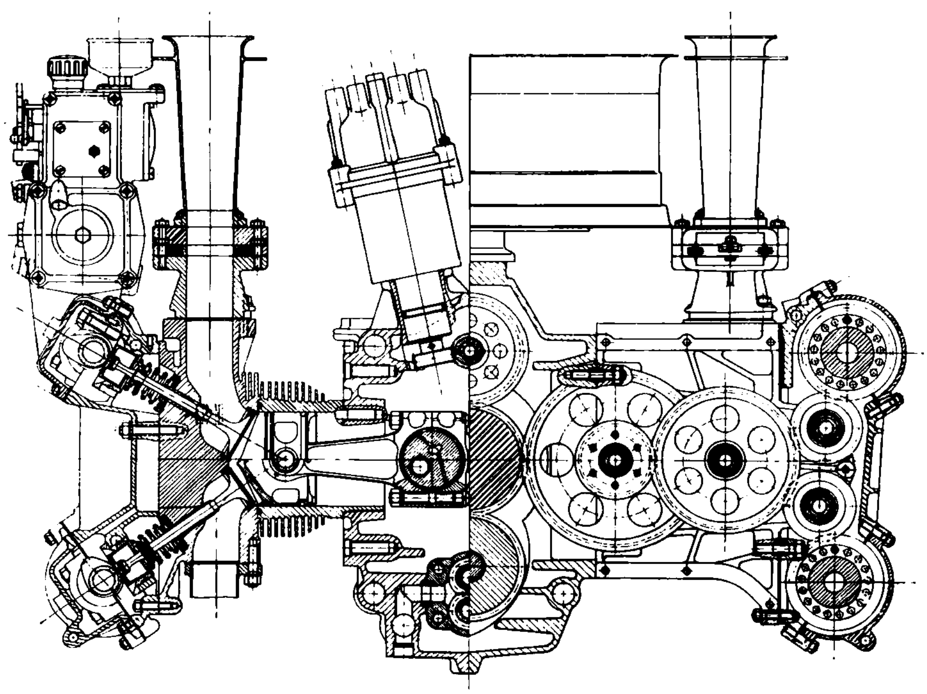

Fig. 6. Cross section of the 917 racing engine

Furthermore, due to the central drive the camshafts are also centrally driven, so that the torsion overlap is a minimum. The pinion at the camshaft has 17 bores and a collar at the camshaft has 16 bores. This differential spacing permits an exact and comparatively simple valve timing adjustment at the fully assembled stage.

At present our experiments on titanium intake valves have reached a stage which permits their use only in short distance races.

Besides their rigidity the cup-shaped cam followers which are used as transmission means between valve and camshaft provide further advantages, namely the admissible values of surface pressure are higher than for rocker arms and the lubrication is less problematic.

An interesting detail is the cam lubrication; oil is sprinkled through a small lubricating perforation, in the cam follower guide, on to the cams. When the valve is in the closed position the lubricating hole is closed by the cam follower itself. The oil outlet is opened only when the cam follower has achieved a lift of approximately 2 mm (0·08 in). Because of this lubricating arrangement the oil consumption of the valve gear can be reduced by about 60 per cent.

Fig. 7 shows the 12-cylinder engine crankshaft of the 917 compared to the crankshaft of the 3 litre 8-cylinder 908 racing engine; the crankshaft of the 6-cylinder Porsche 911 production engine and the Carrerra 6 racing engine. While with the flat-8 and flat-6 crankshafts only one connecting rod is positioned at each crankpin, the crankshaft of the 917, like a V engine, has two connecting rods per crankpin.

The 6-cylinder crankshaft has six crankpins and seven main bearing pins; the 8-cylinder crankshaft has eight crankpins and nine main bearing pins. With its only six crankpins and eight main bearing pins the crankshaft of the 12-cylinder engine is comparatively simple in shape, as can be seen in Fig. 7, with reference to the two other crankshafts. If the 917 crankshaft had been based on the design principle of one connecting rod per crankpin of the 6- and 8-cylinder engine crankshafts, it would have needed twelve crankpins, fourteen main bearing pins and a smaller torsional strength on the side.

The principle of the two connecting rods which could not be realized in the flat-8 engine as it would have implied a less favourable firing order permitted a reduction of the crankpin diameter to 52 mm (2·047 in) for the 917 in spite of its larger cylinder units compared to the 57 mm (2·244 in) of the 8-cylinder engine.

In view of the smaller number of bearings a reduction of the frictional loss could be expected and it was possible to enlarge the width of the main and connecting-rod bearings, a measure which is known to improve lubrication

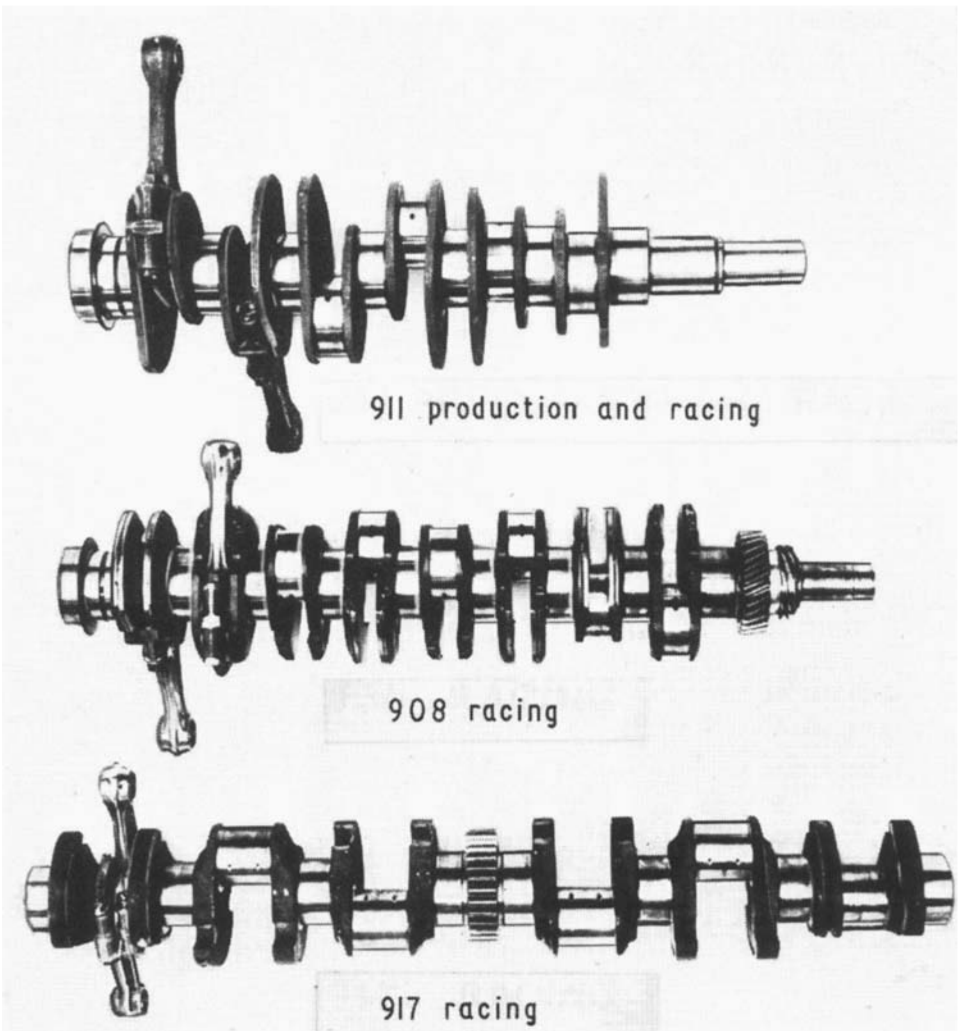

Fig. 7. Crankshafts of the Porsche engines

properties. Furthermore greater bearing widths entail a smaller oil throughput and thus less splashing.

The arrangement of the two connecting-rods per crankpin led to a reduced engine length, as the eccentric relation between the two cylinder banks does not correspond to one half of the cylinder spacing of 118 mm (4·65 in) but only to the width of the connecting-rod bearings, i.e. 24 mm (0·945 in).

With the exception of the 12-cylinder engine crankshaft the crankshafts of all Porsche engines which are now in production are made from heat-treated steel and tufftrided. This is a surface treatment in a salt bath at 570°C. Our measurements showed an increase of up to 50 per cent of the fatigue strength for tufftrided crankshafts. We could thus replace the originally used chrome–molybdenum steel in our 911 production engines (42 Cr Mo 4) by the less expensive carbon steel (Ck 45). Porsche uses tufftride or 'Tenifer' treatment for camshafts also.

The crankshaft of the 917 engine is made from chrome–nickel steel 17 Cr Ni Mo 6, as this shaft has to be case hardened because of its central drive.

There is another version of the 12-cylinder engine crankshaft in which the two crankshaft halves are made from tufftrided heat treated steel and electron beam welded to the case-hardened pinion.

One of the criteria of high-performance engines is the lubrication quality of the connecting-rod bearings. Fig. 8 shows the connecting-rod bearing lubrication of the Porsche engine, types 911, 908 and 917. In the 6- and 8-cylinder engines the oil is transported radially into the crankshaft which it reaches in two places—via the first main bearing and an additional supply bearing at the opposite end of the crankshaft—from where it reaches the connecting-rod bearings through a system of perforations. This lubrication method requires a high oil pressure at high engine speed.

The oil feeding system of the 917 engine is different. It is more efficient because it is almost independent of the engine speed and requires a lower oil pressure. Because of the central drive the crankshaft ends of this engine are free and lubricating oil is fed into the shaft axially from both sides.

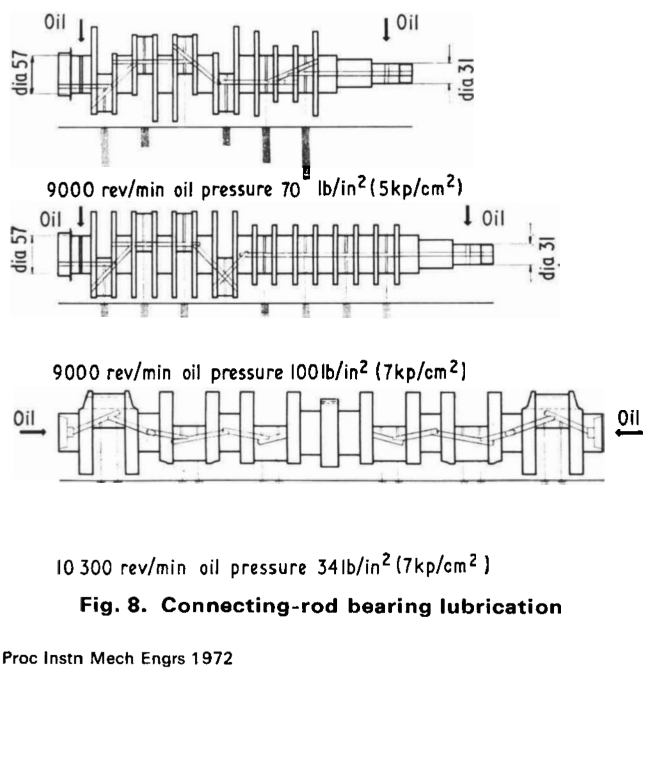

Fig. 8. Connecting-rod bearing lubrication

My company ran comparative tests with the three crankshafts which produced the following results: for the 6-cylinder crankshaft 5 kp/cm^2 (70 lb/in^2) were required to provide an adequate oil supply at an engine speed of 9000 rev/min; the longer 8-cylinder engine shaft required 7 kp/cm^2 (100 lb/in^2) for the same engine speed, but in the case of the 917 crankshaft 2·4 kp/cm^2 (34 lb/in^2) were sufficient even at speeds of 10 300 to 10 500 rev/min.

The oil circuit is an important feature of every high performance engine. It is one of the major factors for engine stability, but also for engine performance. On the one hand all bearings, pinions and cams need an adequate oil supply; on the other hand it is necessary to keep oil throughput at a minimum in order to avoid splashing losses as far as possible. The design of the 12-cylinder engine was aiming at a lubricating system with minimum splashing. The engine was so 'dry' that in its early stages there arose certain difficulties with the piston temperatures. On the other hand, the quite exceptional performance of the engine in its first bench tests in March 1969 justified all efforts.

Fig. 9 shows the oil circuit of the 917 engine; it is a dry sump lubrication which is standard for racing engines. The main oil pump is divided into two scavenging pumps, scavenging the front and rear crankcase and the pressure pump, and is located in the crankcase (see Fig. 5).

The oil filter case contains an adjustable pressure relief valve which maintains a constant pressure of 5 kp/cm^2 (70 lb/in^2) for the crankshaft assembly. The oil expelled by the relief valve is not fed back into the crankcase. It returns directly to the pressure pump.

A throttle valve reduces the oil pressure for the cams and camshaft bearings to 3 kp/cm^2 (43 lb/in^2). Four small scavenging pumps at the ends of the exhaust camshafts will keep the camshaft housing as dry as possible.

As it has been shown, this engine has seven oil pumps, six of which work as scavenging pumps; the extracted oil is transported to the oil tank. When the oil temperature rises above 85°C, a thermostat operates and the oil flows through the oil cooler at the front of the car.

In general it could be stated that for the 917 racing car, steel is used only if and where titanium and other light alloys are not or less suitable.

A special problem had to be solved in connection with the vertically divided crankcase and the mounting of the cylinder heads. The two-bolt connections are shown in Fig. 10.

Magnesium and aluminium have a mean coefficient of thermal expansion of approximately 22×10^{-6} to 24×10^{-6} per degree centigrade.

The corresponding value for titanium is $8{\cdot}2 \times 10^{-6}$. The combination of a titanium bolt and a magnesium or aluminium part causes the bolt to expand only about one third of the expansion of the corresponding part. The 'cold' initial stress is thus enhanced by an additional expansion differential which will either induce a bolt rupture or a distortion of the magnesium or aluminium parts which in turn entails an undesirable reduction of the initial stress.

If normal steel bolts of a thermal expansion coefficient of $11{\cdot}5 \times 10^{-6}$—which is about half of that of magnesium or aluminium—are used, the difficulties are essentially the same. The solution of the crankcase and cylinder head bolt problem was found to be Dilavar. This is a special

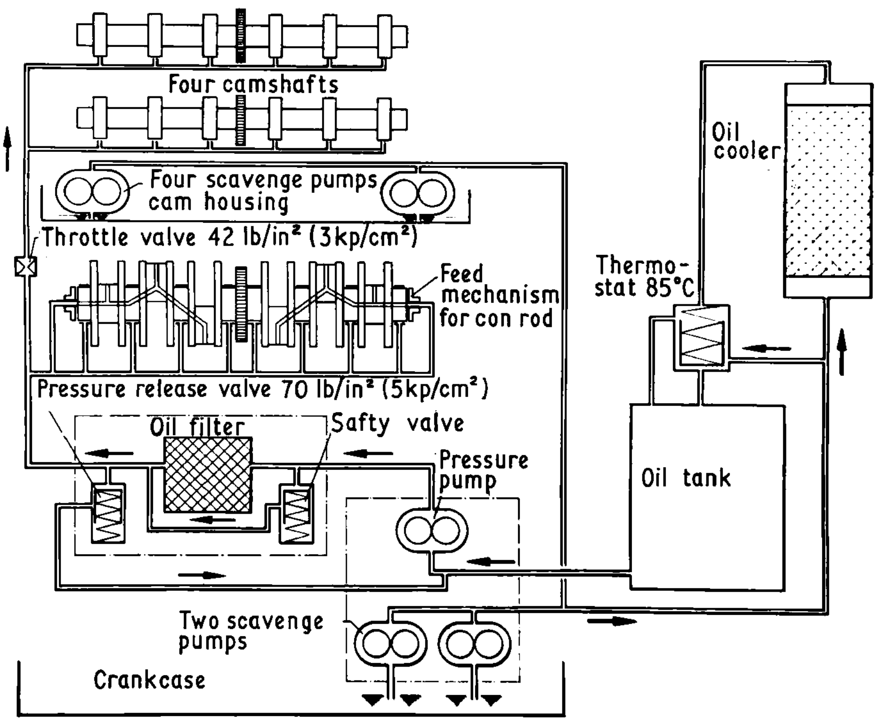

Fig. 9. Oil circulation of the 917 racing engine

steel alloy having a thermal expansion coefficient of approximately 20×10^{-6} per degree centigrade. When the engine is heated, Dilavar bolts will thus expand almost at the same rate as magnesium and aluminium. In addition the cylinder head bolts are insulated by fibreglass, otherwise the cooling air flow would cause the temperature level of the bolt to fall far below that of the cylinder.

Section A in Fig. 10 shows a bolt/nut combination of the type used for the crankcase assembly. Ruptures tended to originate from the last screw winding under load—this is known to be the highest stress region, where the load is increased by a notch effect. All risks were eliminated by replacing the flat washers with spherical ones which avoid bending stress in the thread windings. Furthermore, the bolt end and the nut were extended and shaped in a way that the female thread projects a few millimetres beyond the bolt thread. This will also reduce the notch effect.

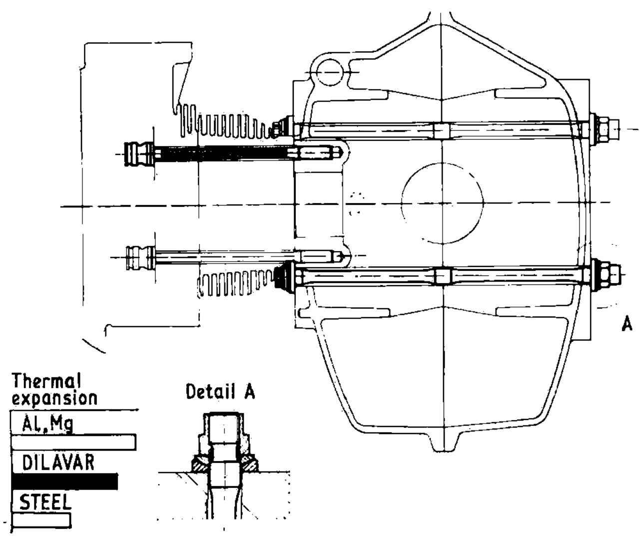

Fig. 10. Crankcase and cylinder head bolts

The first titanium part used by Porsche in a car construction was a connecting-rod 10 years ago. Since that time all our racing engines use titanium connecting-rods, and a lot of experience about the possibilities of this light but high-strength material has accumulated. Today, price considerations are the only obstacle preventing application to production cars. For forged parts the price in titanium is about twenty times that in steel.

In the design of titanium parts the higher notch impact sensibility of titanium compared to steel has to be taken into account. Forged parts need larger transition radii, i.e. softer contours, as the flow characteristics of titanium are inferior to those of steel.

Furthermore the sliding characteristics of titanium are inadequate. In most applications this disadvantage can be eliminated by a surface treatment or coating such as flame plating. Porsche uses a surface treatment called 'Tiduran' to improve the sliding characteristics. Tiduran means a normally two-hours treatment in a cyanogen bath at 800°C.

Fig. 11 shows the forged connecting-rods used by Porsche: on the left the steel connecting-rod of the 911 6-cylinder production type weighing approximately 0·680 kg (1·5 lb), in the centre the titanium connecting-rod of the 8-cylinder racing engine, 908, weighing 0·420 kg (0·92 lb) and on the right-hand side the 917 titanium connecting-rod weighing 0·420 kg (0·92 lb).

The bolts for the titanium connecting-rods are also made from titanium. The corresponding bearings are shown below the connecting-rods. Collar end bearings are used for racing engines. These bearings provide a smaller oil throughput and improve lubrication properties.

The air-cooled Porsche engines have individual cylinders. Fig. 12 shows three different types of cylinders and the corresponding pistons. The 2·2 litre production engine 911T producing 125 hp uses cast-iron cylinders. The 155 hp and 180 hp 911 production engines use so-called

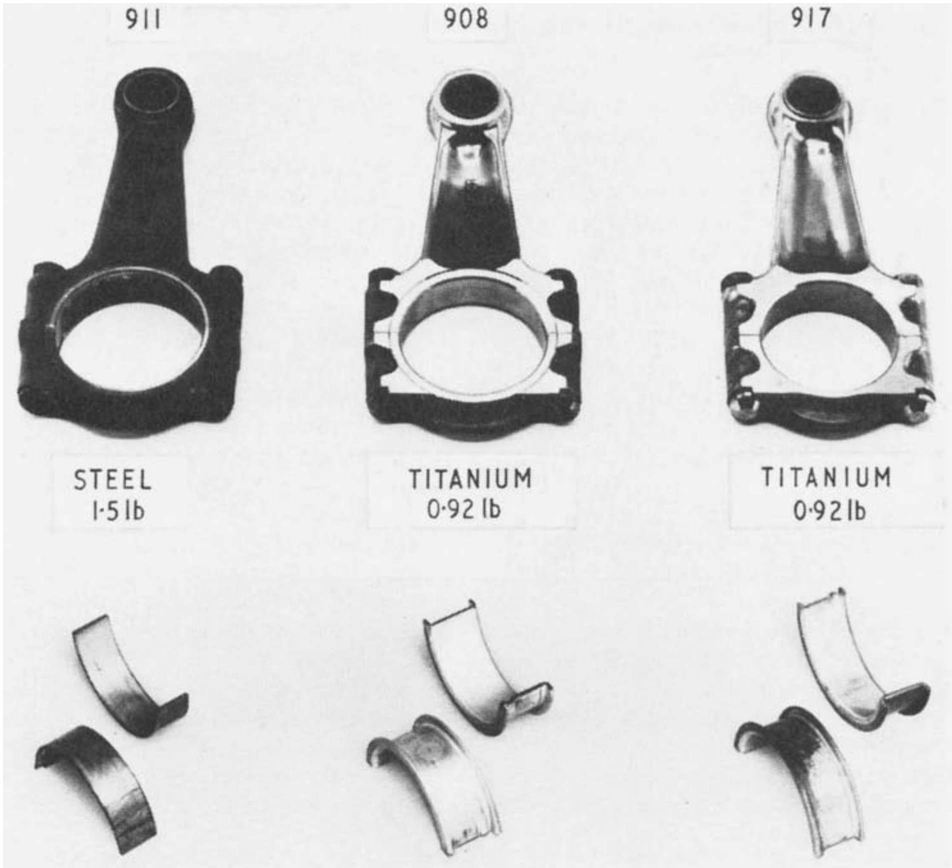

Fig. 11. Connecting-rods of the 911, 908 and 917 engines

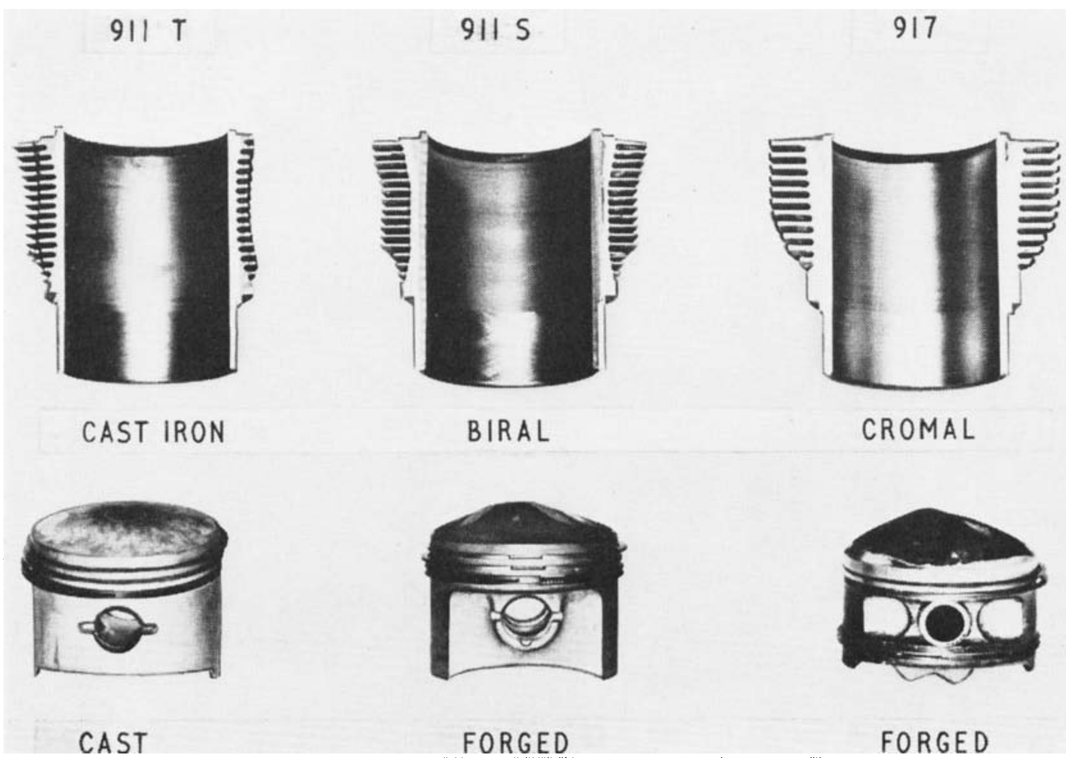

Fig. 12. Cylinder and piston of the 911 and 917 engines

'Biral' cylinders. A Biral cylinder consists of a cast-iron cylinder barrel around which aluminium is cast in a die-casting process.

Like all racing engines the 917 has Cromal cylinders. These cylinders are forged from an aluminium alloy, machined and then coated with a chrome sliding layer. Small holes are rolled into the chrome layer, these holes absorb oil and thus improve the sliding properties.

The pistons of the racing engines and the 180 hp production engines are forged in aluminium. All other production types use cast aluminium pistons.

One of the individual cylinder heads of the 917 engine is shown in Fig. 13. The cylinder heads are chilled in an iron mould from a heat-resistant aluminium alloy. The cylinder head is the only aluminium casting of the engine. As already mentioned all other castings are made from the still lighter magnesium.

The combustion chamber is formed by the spherical cylinder head surface and a spherical-shaped piston crown. The axes of the intake and exhaust valves intersect in the centre of the cylinder head sphere.

The combustion chamber design shown in Fig. 13 has also achieved optimum results for production engines. The position of the two sparking plugs whose platinum electrodes protrude into the combustion chamber creates short combustion paths. This kind of combustion chamber has a small surface, shows no fissures and induces an optimum combustion process as indicated by the favourable late ignition point of 27° crank angle before top dead centre (t.d.c.).

The cylinder head seal shown in Fig. 13 which Porsche has been using for years in all engines works without any problem. It consists of a C-shaped metal coat into which a hose spring has been inserted.

Porsche have been using fuel injection in their racing engines for several years. The injection pump of the 12-cylinder engine was developed for this particular type of engine. Each engine cylinder possesses its own plunger. These plungers are arranged in two banks in a magnesium housing (see Fig. 3) and are actuated by cams. The fuel volume is controlled via a three-dimensional cam dependent on the position of the throttle slides and the engine speed. Nylon tubes are used as injection ducts. They are all of the same length in order to avoid deviations in the injected fuel volume and the injection point between the individual cylinders. The injection valves have an ejecting pressure of 18 kp/cm^2 (255 lb/in^2) and are located at the upper rim of the induction funnels, as optimum performance is achieved when the injection point is located at the greatest possible distance from the intake valve.

In order to avoid the accumulation of fuel in the induction system when the slide is in the closed position—for instance during the braking process when entering a curve—the specially shaped three-dimensional cam will interrupt the fuel supply at an engine speed of more than

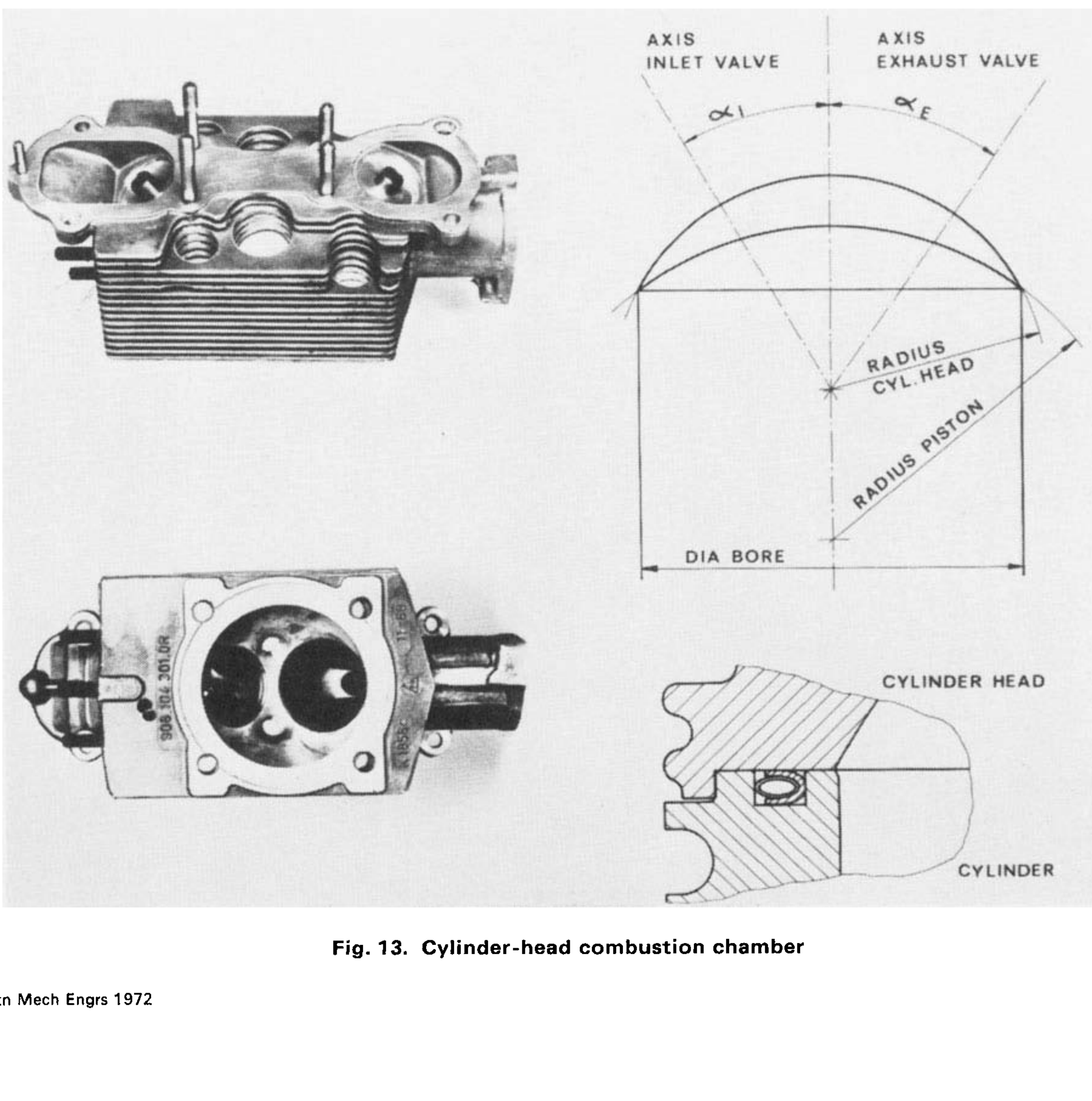

Fig. 13. Cylinder-head combustion chamber

4000 rev/min. Below this speed the injection volume will again increase to the volume required for idle. A pressure transducer adjusts the injection volume dependent on ambient pressure.

The Porsche production cars 911E and 911S work on the same principle as the described injection system of the 917.

The cooling blower is arranged horizontally above the engine. It has a diameter of 330 mm (13 in) and supplies the cooling air for the engine at a rate of approximately 2400 l/s at the rated engine performance. The blower is driven via bevel gears at a ratio of 17:19 of engine speed. As already mentioned, at maximum engine power the power input to the blower is 17 hp, i.e. 2·7 per cent of the engine performance. Of the entire cooling air volume 65 per cent is used to cool the cylinder heads and 35 per cent for the cylinders.

3 POWER TRANSMISSION

Porsche develop not only all gearboxes for their own use but also for other companies. There is a special Porsche locking synchronization which is built by other companies under licence—our racing-car gearboxes use this synchronization system.

Fig. 14 shows the 917 gearbox. It is designed for five forward gears and one reverse gear. During actual use it was shown that in view of the wide speed range and the flexible behaviour of the 12-cylinder engine, a four-gear version is completely satisfactory for most race-tracks.

A gear pump is located at the rear end of the clutch shaft, its purpose being to sprinkle oil to the crown and pinion and the gear wheels.

The gearbox is equipped with a laminated differential locking device with adjustable (in our case about 75 per cent) locking ratio.

The gear cases are cast in the heat-resistant magnesium alloy RZ 5 (ZE 41 A) and weigh 21·3 kg (47 lb). The same material is used for the engine castings.

Fig. 14 also shows a triple disc clutch used in the 917. The driven clutch discs are only about 2·5 mm ($\frac{1}{10}$ in) wide and use sinter pads.

4 CHASSIS AND BODY

The design of a racing car is defined by the sports regulations, the road performance and safety considerations. Apart from certain prescriptions with reference to the internal dimensions of the cockpit, the tank volume and

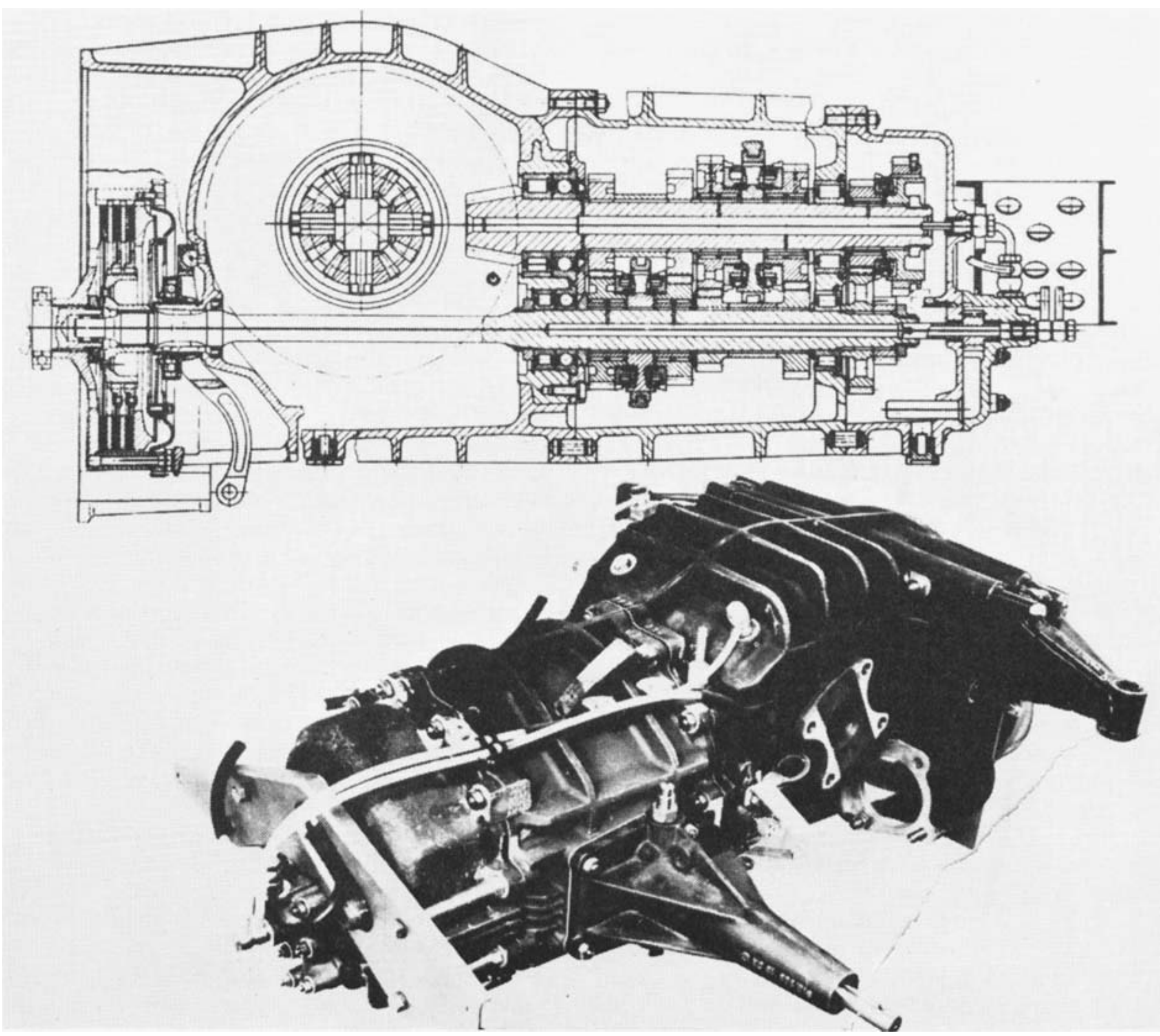

Fig. 14. Transmission of the 917 racing car

the minimum weight, etc., the task of a racing car designer can generally be worded as follows: how to create a car which will run a predetermined racing distance at a workable effort of the driver and without any risk to the driver's health in the shortest possible time. This has to be taken into account in the solution of all detail problems of racing car technology. Not only the smallest air resistance, the lowest weight or a maximum value of the attainable transverse acceleration of the car alone are decisive, but an optimum result of the entire task.

A racing car which is thought to be the car without compromise is actually an ideal compromise representing the most favourable combination of all pertinent factors like weight, engine power, air resistance, lateral load, straight-on drive, braking performance, fuel consumption, wear of tyres and brake pads. The driver's comfort, i.e. seating position, visibility, use of pedals, steering wheel and gearshift, readability of controls and cockpit air conditioning are also important.

Finally the influence of a psychological aspect should not be forgotten. The real speed of a racing car is not primarily determined by the engine power and different kinds of driving resistances but by the confidence of an experienced driver with a sense of responsibility in the car, expressed in the speed he dares to realize without risks. The driver needs a feeling that the car will not act uncontrollably in limiting conditions but will respond exactly to his intentions.

Porsche have invested a lot of time and effort in lightweight structure and safety—there is a direct connection between the two. Research activities in this direction have continued steadily for years—and quite successfully. This continuous progress in the field of lightweight structures has not only secured Porsche's predominance in the construction of extremely light racing or performance cars, but it has also created vital knowledge for the progress of technology.

Of course lightweight structure is a genuine and justified improvement only if safety is warranted. No part which is susceptible to failure or influences safety is applied without testing.

The racing cars are subject to an endurance shatter test on the Porsche testing grounds to try out the chassis and chassis parts; this means a much higher stress than on racing tracks.

The engine is subject to an 18 h endurance bench test at full load.

The power transmission parts are tested in a specially defined race-track simulation programme on the chassis dynamometer including all pertinent gearshifts, acceleration and braking modes.

It is hardly justified to send a car to races without extensive preliminary testing. But of course even the most thorough preparations will not be a 100 per cent guarantee for success; unpredictable events arise during each race and may jeopardize success. For instance there were a lot of tyre failures during the past few years. This, among other things, is due to the fact that the tyres of today are subject to higher stresses induced by the greater lateral acceleration and speed attained by modern racing cars. Besides the breaking away of tyre treads most of the failures were due to the tyre bead lifting or being pressed away from the rim so that the air could escape rapidly. This has been remedied by the incorporation of a hump at the outer periphery of the rim, besides the tyre bead.

As well as the measures of active safety—such as the extensive mechanical chassis test on the shatter track—the 917 has been equipped with passive safety devices, part of which are prescribed by F.I.A.

The fuel, the volume of which is restricted by regulations to 120 l (26·4 Imperial gal.) is contained in a receptacle constructed as a safety tank. The tank has a flexible outer coating which is resistant to shocks and flames and is filled with polyurethane foam. This foam material which fills 3–5 per cent of the volume serves several purposes. It prevents the collapsing of the tank and the wobbling of its contents. Furthermore it serves as a flame barrier acting against explosion of the fuel–air mixture and induces the fuel to leak out only slowly through a possible hole. The safety fuel tank is located in an aluminium cup on the right-hand side of the car between the front and rear wheel.

Furthermore the 917 possesses a fire extinguishing system which can be brought into effect either manually or automatically via a temperature or acceleration switch or optically. The system works by means of a gas (Halon 1211—bromchloride fluormethane, $C\,Br\,Cl\,F_2$) which is conducted to the critical places of the car, like cockpit, tank and engine compartment where it can emerge through a multitude of small perforations.

Two clearly marked switches—one is accessible from the driver's seat, the other from the outside—permit the interruption of the electric circuit.

Finally the 917 is equipped with a safety belt and an effective three-dimensionally supported roll-bar made from 45 mm (1·77 in) tube.

In 1967 Porsche developed a tubular chassis made from aluminium tubes for a light 2 litre racing car which was to run in the events for the European hill-climb championship. The distance of hill climbs was very short, so that checking intervals were equally small.

A failure of the tubular chassis was hardly to be expected, as the car had, of course, been tested on the jolting track. Even so the tubular chassis was regularly checked. For easier tracing of possible cracks the hollow spaces of all tubes under load were connected by perforations and the tubular system was filled with compressed air. In this way a dependable check of the state of the tubular frame was possible at any time by measuring the air pressure in a pressure gauge. A crack in a frame tube would immediately induce a sharp pressure decrease.

Early in 1968 a racing car using an aluminium tubular frame was used in a long-distance race; a 2·2 litre 907 car finished the 24 h of Daytona. That same car had already completed almost 30 h of practice on the same track before the race. In our experience aluminium tubes are excellent and we could use this material for the 917 frame without reservations.

Fig. 15 shows this frame which weighs 47 kg (104 lb) complete with all suspension parts and fixtures but without the tank cup. Depending on the load intensity, tubes of one of the following dimensions is applied: $20\times1{\cdot}6$ mm ($0{\cdot}79\times0{\cdot}063$ in), $25\times1{\cdot}6$ mm ($1\times0{\cdot}063$ in), $30\times1{\cdot}6$ mm ($1{\cdot}18\times0{\cdot}063$ in), $32\times2{\cdot}5$ mm ($1{\cdot}26\times0{\cdot}1$ in) and 35×3 mm ($1{\cdot}38\times0{\cdot}118$ in).

The strength of the tube is 38 kp/mm^2 (52·500 lb/in^2); the tube connections are effected by shielded arc welding.

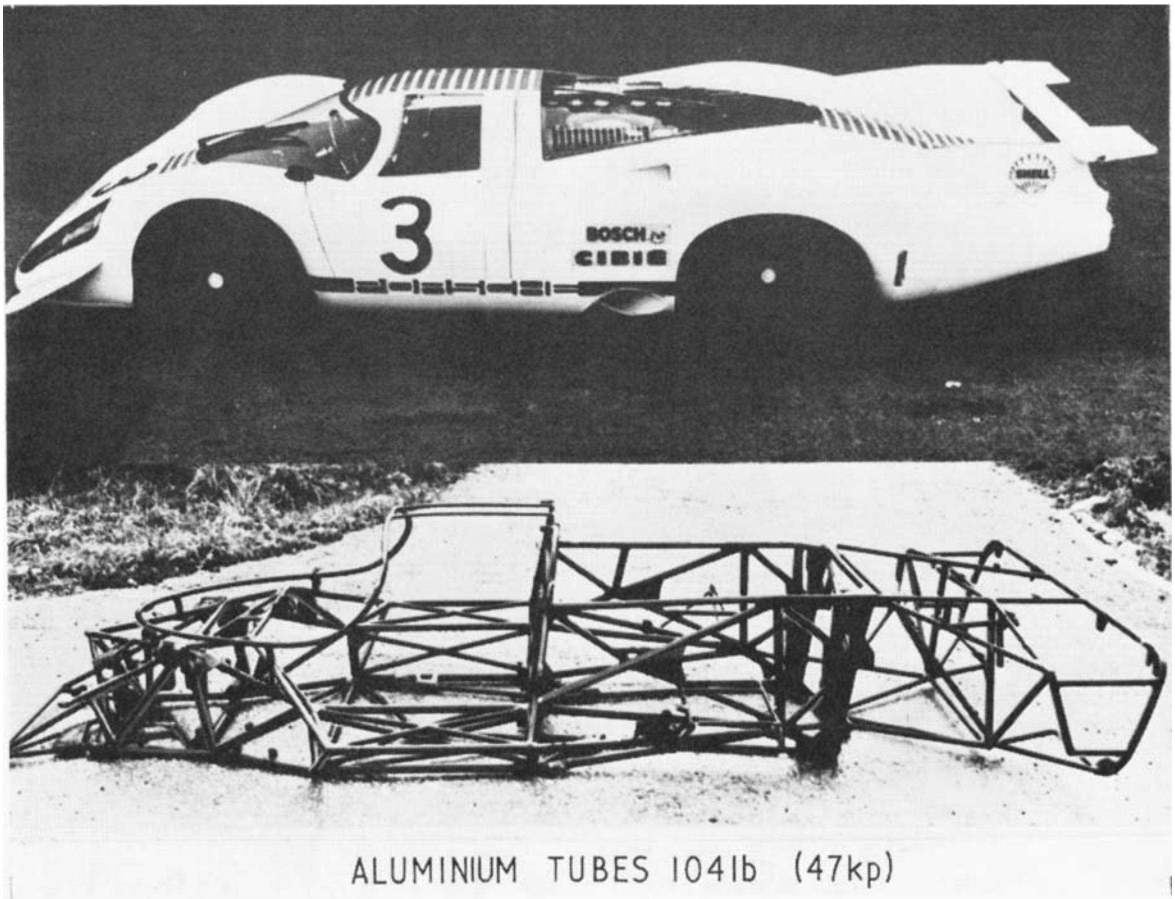

Fig. 15. Tubular frame of the 917 racing car

Some of the tubes serve as supply and return ducts for the oil cooler in the car nose in order to save oil hoses.

During the past few years racing tyres experienced a remarkable development. Their cross section became lower and their contact area wider and almost flat. For instance, the contact width of the 917's rear tyres is approximately 380 mm (15 in). The racing tyres which are used at present are able to transmit longitudinal and transverse accelerations of $1{\cdot}4g$ and more—always provided that the wheel position with reference to the ground surface is right. Balanced wheel kinematics and an optimum suspension and stabilizer adjustment are required to take full advantage of the features of modern racing tyres. Exact wheel guiding is of the same importance as kinematics. Elastic distortions of the wheel suspension—of the frame or of the suspension arm side—should be as small as possible. Rubber bearings which are usually used in production cars, formerly also in racing cars, are therefore to be avoided.

The wheels of the 917 are suspended at double transverse suspension arms. This suspension system represents an optimum solution for the numerous requirements. It is light and provides ample tolerance for the adjustment of wheel kinematics.

Fig. 16 shows the suspension and mounting of the 917 front wheel. The longitudinal load is borne by longitudinal wheel suspension struts with a wide base at the tubular frame—this is not visible in the figure—an arrangement which will ensure more accurate steering as well as a more favourable load transmission to the tubular frame.

Solid-drawn aluminium pipes are used for those suspension arms which are exclusively subject to tensile stress and pressure—not to bending loads. The ends of these tubes into which threads are screwed are rolled conically.

The ball pivots on the wheel side are adjustable and have a titanium housing. The spherical bearings of the suspension arms on the chassis side are equipped with Teflon bushings and are made from titanium. The front and rear uprights as well as the 15-in rims are cast in magnesium.

The front and rear wheel hubs are made from a titanium alloy; the mounting cup of the brake disc and the central nut are forged from an aluminium alloy.

Fig. 16 also shows the rack and pinion steering gear with its titanium rack and pinion and its magnesium-cast housing.

The suspension springs of the 917 are made from titanium. The required progressive characteristic of this spring is not achieved by the usual variation of coil upgrades but by a conical grinding of the titanium wire as it is shown by the photograph.

Besides the already mentioned factors of wheel kinematics and steering, the amount of unsprung weights will equally exert a major influence on the qualities of road behaviour. On corrugated or uneven roads the wells and the suspension system are subject to inertia forces. These forces are transferred to the chassis via the suspension springs and the shock absorbers and affect the road behaviour to a greater or lesser extent dependent on their magnitude. In certain cases they may induce the

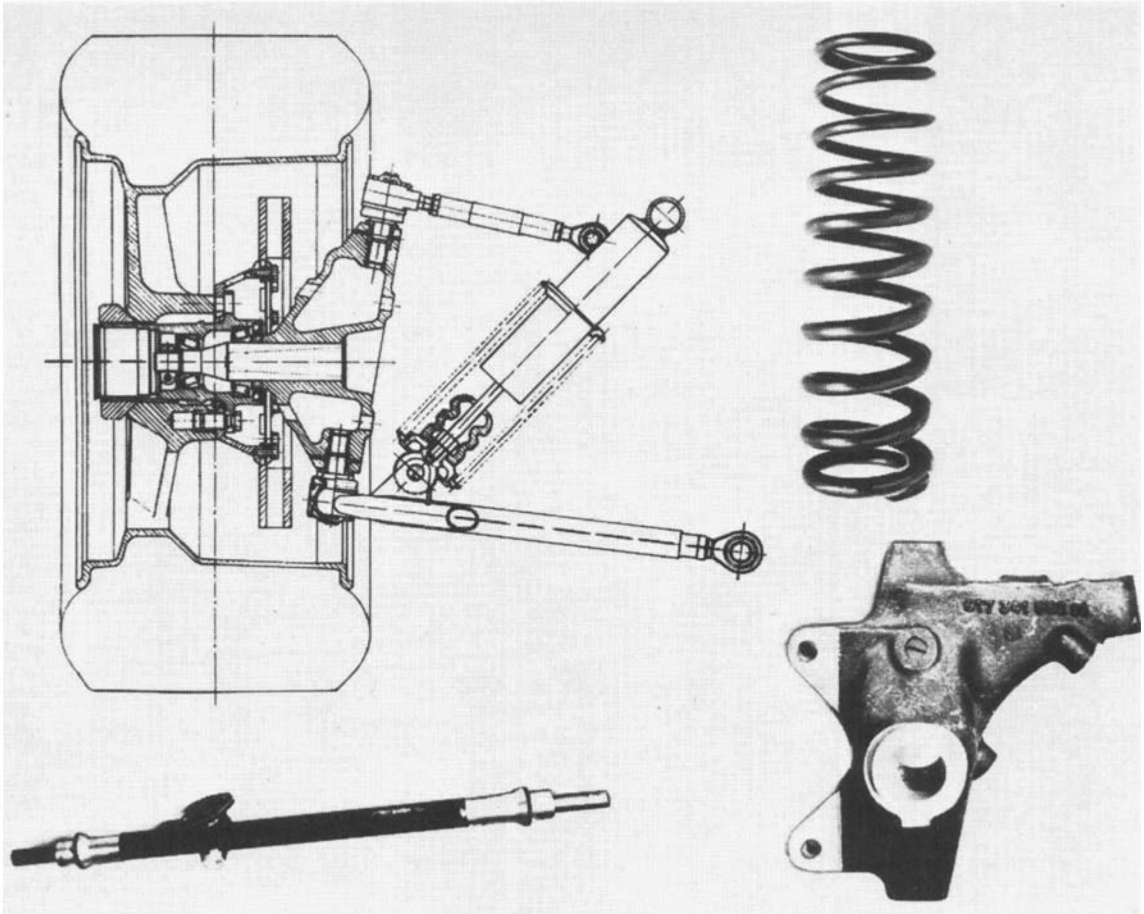

Fig. 16. Front suspension of the 917 racing car

wheels to lift off the ground, i.e. a loss of the necessary contact between the tyres and the road surface. As the magnitude of the detrimental forces is proportional to the amount of unsprung weight, it is necessary to make the corresponding parts as light as possible—within the safety limits. At present the 917 has already achieved a satisfactory level by using titanium, aluminium and magnesium; nevertheless development efforts continue in this direction.

The brake calipers and the 28 mm (1·1 in) wide internally ventilated brake disc made from special cast iron make up approximately 9 kg (20 lb) per wheel, i.e. a major part of the unsprung weight. Combined with the functional improvements of the braking system continued efforts are made towards a weight reduction of these relatively heavy parts. Porsche has its own braking test-bed in which all improvements and weight reductions of the brake calipers, the pistons, the braking hoses, pads, discs, etc. are tested.

The ability of the braking system to meet any emergency of the 917 which weighs 970 kg (2150 lb) with its tank full and attains a top speed of approximately 385 km/h (239 mile/h) are high. The braking performance is not only a matter of safety, it also exerts a direct influence on the driving performance. In racing conditions, the braking time of the 917 is about 15–18 per cent of the total.

The 917 has a dual circuit braking system incorporating one main cylinder each for the front and rear wheels. An adjustable swingletree is located between the brake pedal and the two cylinders and allows for an accurate adjustment of the brake force distribution between front and rear.

The brake caliper is made from aluminium and has four pistons. The front wheel brakes which are subject to a major part of the load receive additional cooling air through air slits in the car nose and hoses.

Fig. 17 shows the mounting and the suspension of the rear wheel and the drive shaft. The rear axle parts are made from the same materials as the corresponding front axle parts; however, some of the parts have larger dimensions than those of the front wheels on account of the higher loads.

The drive shaft which is shown in Fig. 17 has two universal joints: a longitudinal adjustment based on ball races and a flexible coupling absorbing the torque shocks. The two parts of the drive shaft which need to be hardened on account of the ball races are forged in steel, the other three shaft parts in a titanium alloy.

The 917 has to be an all-round racing car as it will be used on very different types of race-tracks; in 1971 the manufacturers' world championship had eleven races.

The Nürburgring track requires cars with a large spring travel stroke—the 917 has about 170 mm (6·7 in)—which complicates the wheel kinematics. Half of this travel stroke is sufficient for Le Mans. For the Nürburgring track the springs should be as soft as possible. Le Mans, however, requires harder springs, as on this fast track large spring movements of the car will, among other things, induce a detrimental effect on the aerodynamic stability.

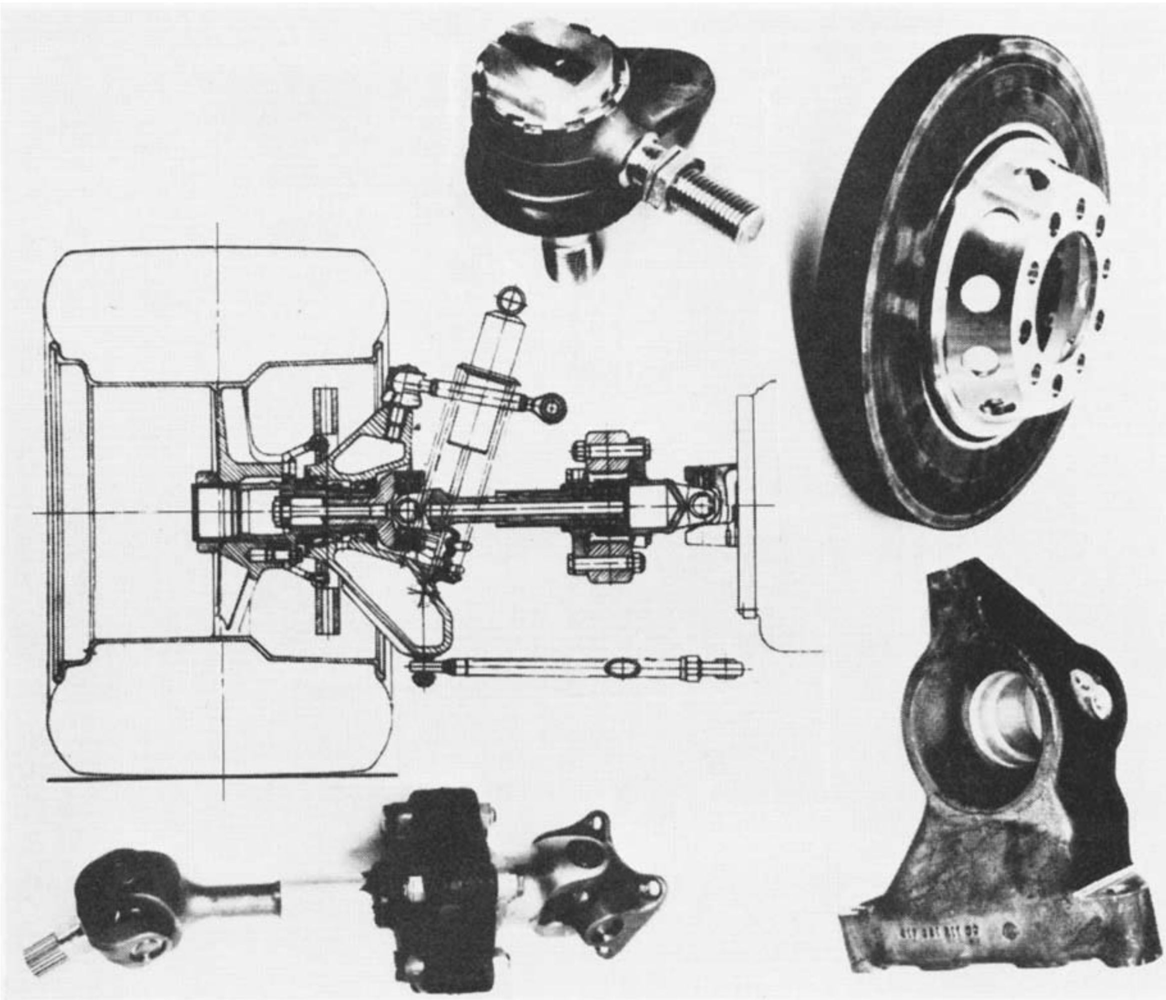

Fig. 17. Rear suspension of the 917 racing car

For Le Mans a car needs excellent straight-on drive characteristics and for the Nürburgring an excellent curve behaviour. At Le Mans 66 per cent of the lap time is driven at full load and about 16 per cent at partial load in curves. On the Nürburgring full load conditions make up only 39 per cent of the lap time, and 46 per cent in curves.

An increase of 10 per cent of the attainable transverse acceleration would reduce the lap time on the Nürburgring to a value which could not be achieved even by doubling the engine power. At Le Mans, however, a 15 per cent increase of the engine power will achieve the same result as a suspension improvement of 10 per cent.

The Porsche racing development also takes advantage of electronic data processing. A computer calculates the race-track lap times which are to be expected and determines the optimum gear ratios for the different kinds of tracks. Furthermore, the race-track programme provides a simple means to determine the measures which will achieve the best results in a special race.

Furthermore, the driving diagrams calculated by the computer have shown that during the races the cars are driven at curve speeds which are even higher than those corresponding to the transverse acceleration values of 1·4 to 1·5*g* determined in the 190 m (600 ft) circle of the Porsche skid pan. This is partly due to the body shape creating downward pressure and thus increasing the wheel load.

Fig. 18 shows the normal version of the 917 racing car. The drag coefficient of the Le Mans winner of 1970 is approximately 0·46. The coefficient of downward pressure is 0·019 on front and 0·351 on rear. It would of course be possible to develop a body shape with a drag coefficient below 0·3 which would mean a top speed of much more than 400 km/h (250 mile/h) for the 630 DIN hp of the 917. However, this value could only be of a theoretical importance as the lack of stability would not permit this high speed even on extremely fast tracks.

The body is not only a housing for the chassis nor a matter of styling. Just as for instance the wheel suspension the body shape is of importance for the road behaviour which will increase with speed and engine power. The body shape cannot be appreciated only in terms of its drag coefficient; the aerodynamic stability has equally to be taken into account. This is also true for racing and production cars.

Test drives with the 917 on a track whose lap times are approximately 1 min 45 s have shown that improvement in lap times of 3 or 4 s can be achieved by body modifications alone. This is a surprisingly high improvement—probably more than a 50 hp increase of engine power would be required to obtain the same improvement.

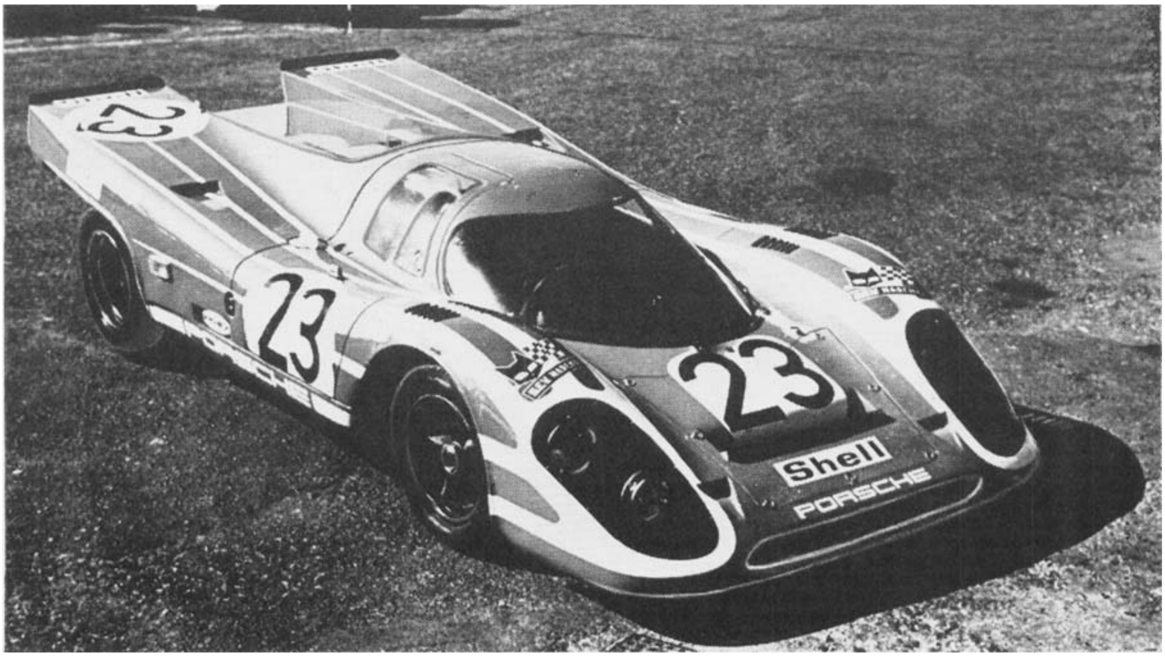

Fig. 18. Sports 917 racing car, 1970 Le Mans winner

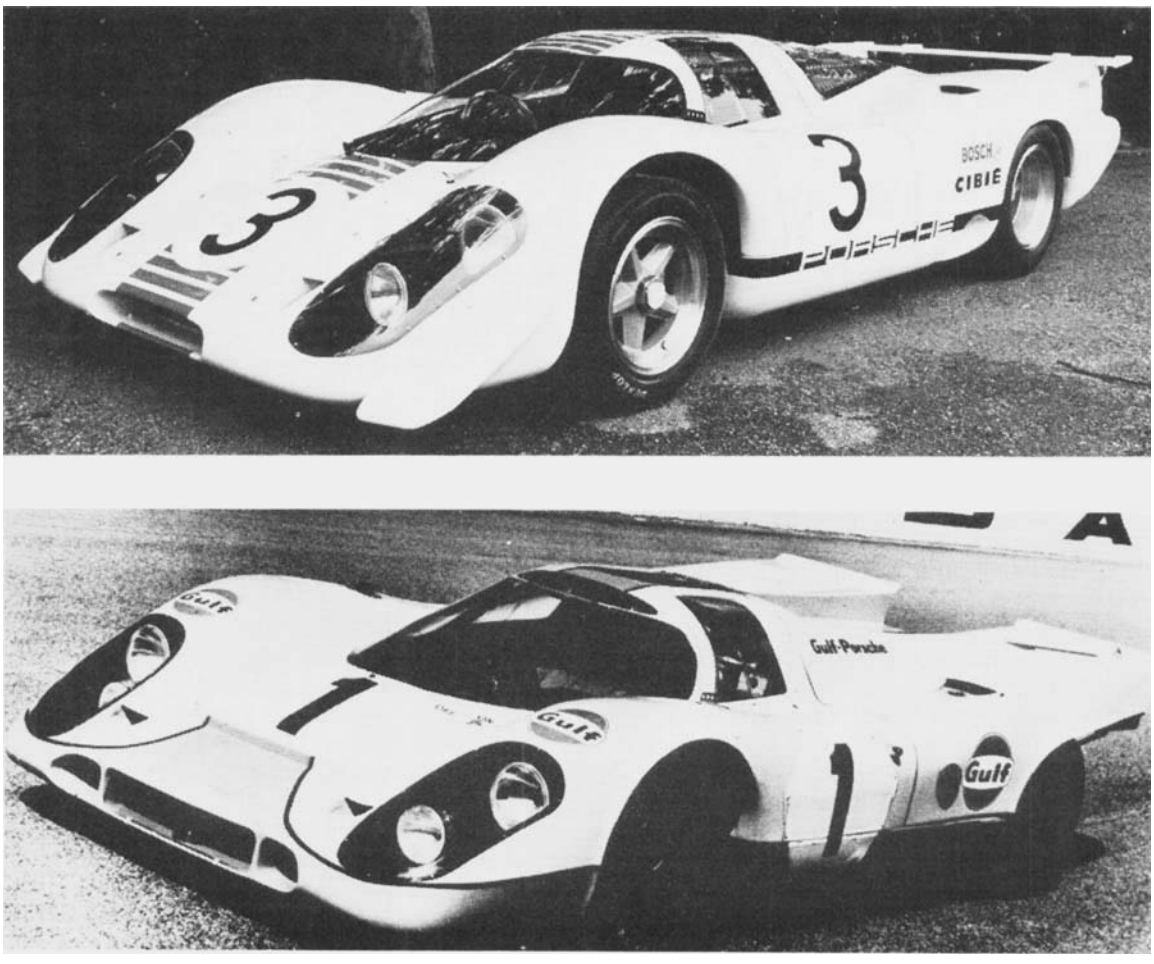

Fig. 19. Sports 917 racing car, Le Mans and normal type

The 4·5 litre 917 which Porsche used for Le Mans in 1969 had two movable spoilers each at its nose and tail. These spoilers were controlled via the spring movements of the wheels in order to take advantage of all aerodynamic possibilities. If the wheel pressure is reduced, i.e. if the wheel springs are extended, the corresponding spoiler surface becomes steeper, so that the ground pressure is automatically enhanced by aerodynamic forces. These aerodynamic stabilizers become effective in each suspension movement of the cars, such as in curves or when crossing ground waves. Fig. 19 shows this Le Mans version of the 917 car compared with the standard body.

In fact the function of these aerodynamic stabilizers can be described as an attempt to maintain the normal position of a car by making use of aerodynamic forces, i.e. the trim and wheel pressures.

At Le Mans in 1969 a car of this type maintained a leading position until the 21st hour when it had to give up on account of damage in the power transmission.

In 1970 a special 917 car was used at Le Mans besides the normal version. Its body has a drag coefficient of 0·360 and was adapted to the special properties of the Le Mans track. In 1970 movable spoilers were no longer admitted.

The Le Mans track has a criteria which is hardly true for any other track; an increase of the top speed, i.e. a reduction of the drag coefficient, is in this case a better contribution to a lap time improvement than an increase of the permissible transverse acceleration of the car. This is due to the fact that the Le Mans track contains a straight track portion of almost 5 km length, so that the time portion of the curve is only about 16 per cent.

Fig. 20 shows the shape of the Le Mans track and the data calculated in advance by the computer. The encircled figures show which gears are used. Braking is marked by the hatched portions. The computer calculated a nominal lap time of 3 min 19·3 s for the Le Mans type 917. In practice the lap time was 3 min 19·8 s. Theoretically of course the special Le Mans car with a drag coefficient of approximately 0·36 should have won. But in racing there will always be a number of unpredictable events, all the more so if a race lasts for 24 h. Among the unpredictable events of Le Mans 1970 were extraordinarily heavy rainfalls which caused complications at the tyres and the ignition of one car as well as a quite exceptional fracture of a valve spring in the second 917 Le Mans car. The race was won by the 917 shown in Fig. 18. Apart from the changing of the tyre due to the weather conditions this car did not suffer from any difficulties. The car had 21 pit stops for refuelling (oil and petrol) and for changing drivers and tyres. During the 24 h of racing the total pit stops made up 29 min 56 s.

The winning car had travelled a distance of 4608 km (2860 mile) and used 2085 litre (459 Imperial gal.) of petrol, which corresponds to a specific consumption of 45·2 litre per 100 km (6·23 mile per Imperial gal.). Second in the overall classification was also a Porsche 917: the special body car with the ignition difficulties. The small air resistance of this car (drag coefficient 0·36 compared to 0·46) caused a substantially reduced fuel consumption, which was 38·6 litre per 100 km (7·3 mile per Imperial gal.) which won the high-doted consumption index.

Since 1964, when the 904 Porsche was produced in a series of 100, the bodies of Porsche racing cars have been made from fibreglass reinforced plastics. This material is highly suitable for application to racing cars as its production procedure favours the manufacture of small to medium quantities.

A thick-walled shell is made from a positive model in original size in fibreglass tissues and artificial resin and will serve as a model from which the body parts are moulded.

The fibreglass parts of the 917 body and its interior panelling weigh about 42 kg (93 lb).

The development of a racing car is neither easier nor

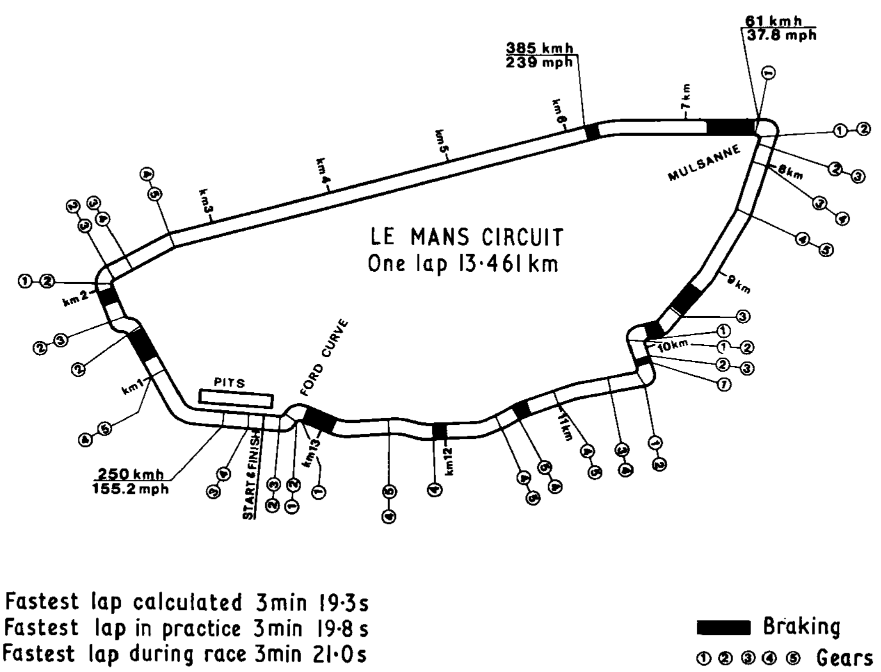

Fig. 20. Computer diagram of Le Mans circuit

more difficult than that of a production car. There is, however, a difference in 'engineering' of the two kinds of cars caused by the different requirements which the racing car, on the one hand, and the production car on the other hand have to fulfil.

Just as the ideal production car, the ideal racing car is an optimum compromise of all requirements.

It is impossible to define the ultimate purpose of automobile racing in one sentence—just as it is impossible to do so for the car in general.

The statement 'the car is a device for transporting persons from A to B' is doubtlessly incorrect or at least incomplete, for if that were all that there is to the phenomenon 'car', then a Rolls-Royce *Silver Ghost* could never have existed.

One extreme is the pure transport vehicle, the other the pure racing car. In between are the cars of people who want to get from A to B. Some of them want to go comfortably, others quickly and others fast and comfortably at the same time.

In the case of a racing car not only the driving but also the designing is fun.