

AIR-COOLED MOTOR ENGINES

JULIUS MACKERLE M. E.

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PREFACE

Direct cooling by air is one of the most effective means for reducing engine-weight in automobiles and commercial vehicles besides securing many other advantages. Its use in certain widely successful European small cars is prompting much new study of its possibilities, notably in Britain and America. But although much work has been done on air-cooled aircraft-engines a comprehensive reference book on these engines for cars has hitherto been lacking and the facts have been scattered in technical journals in many countries. It was to meet this need that the Author prepared the present book.

The first part deals with the fundamentals of heat transfer from hot gases through cylinder walls, and its removal from finned cylinders to the atmosphere. Special attention is paid to cooling control and utilization of waste heat. The second goes into design details of individual parts of the engine (especially where they differ from the corresponding features with liquid-cooling); choice of parameters, and the general concept of the engine design. All conclusions are based upon long and varied practical experience, and will it is hoped prove of value in the solution of problems encountered by designers. Many of the specific details may well interest a wide circle of draughtsmen in the motor car, motor cycle and aero industries.

The first, theoretical, and the second, practical, parts are complemented by an extensive survey of air-cooled engines produced by leading manufacturers of all countries and illustrations and diagrams are very freely used to elucidate the discussion. The tables, formulae and nomogram should make the volume additionally useful for reference.

In most instances British equivalents of the original metric units have been added, but it is felt that for certain detailed dimensions relating to engine specifications the British engineer is sufficiently familiar with metric units to leave these unconverted. A table of metric conversion factors is included.

J. MACKERLE

E. H. MACLACHLAN

METRIC CONVERSION FACTORS

1 mm	0.039 in
1 cm	0.39 in
1 m	3.28 ft or 1.094 yd
1 km	0.621 miles
1 cm ²	0.155 in ²
1 m ²	10.763 ft ²
1 cm ³	0.061 in ³
1 m ³	35.314 ft ³
1 litre	0.219 gal (Imperial) or 0.264 gal (U.S.)
1 kg	2.204 lb
1 kg/cm ²	14.223 lb/in ²
1 kgm	7.233 ft-lb
1 kcal	3.968 B.t.u.
1 kg/m	0.671 lb/ft
1 litre/100 km	0.354 Imp. gal/100 miles
1 km/litre	2.87 miles/Imp.gal
1 metric horse power	0.987 b.h.p.

FIRST PART

THEORY

CHAPTER I

GENERAL PRINCIPLES

1. Advantages of air-cooled engines

It is correct say that all vehicle engines are air-cooled. Even in water-cooled engines heat is transmitted first from cylinder to water and afterwards, in the radiator, from water to air. This method of cooling by water is easy to accomplish, because the heat taken off the hot cylinder walls by water can be distributed without difficulty upon the large cooling surface of the radiator, and so the easy transmission of heat to air is made possible. Most vehicle engines are cooled by water; however, the great advantages of cooling engines by air are gradually being recognized.

Reciprocating engines used in aircraft are almost entirely air-cooled. Aircraft engines cooled by air are manufactured to-day in sizes ranging from 50 to 3500 h. p. and they have superseded water-cooled engines. The principal advantages of air-cooled aircraft engines are low weight, and greater reliability in operation. Nearly all transport air-liners are equipped with air-cooled engines. Their minimum fuel consumption at economical speeds amounts to about 0.39 to 0.48 lb/b.h.p.-h (180 to 220 g/b.h.p.-h.).

Modern motor cycles also are designed almost exclusively with air-cooled engines; with them, as with aircraft, sufficient cooling air is provided by the flow due to the motion of the vehicle, and no special cooling fans are required.* Air-cooled motor cycle engines have high specific performances, and they are equal to the best water-cooled engines. New designs of air-cooled vehicle engines are notable for their easy maintenance, reliability and economical operation.

In the internal combustion engine only one third of the heat energy contained in the fuel is converted into work, one third is lost in the exhaust gases, and one third is carried off by cooling. This distribution of available energy is approximate only, the exact relation depends on specific factors such as engine design, type of fuel, cooling system, etc. Heat carried off by cooling must be considered as a definite loss, because apart from the fact that no useful work can be obtained from it, part of the engine performance is frequently used for its removal. Therefore, every endeavour must be made to keep this loss of heat energy at a minimum.

* Recently special cooling fans have been mounted in some aircraft engines (see Chapter VI.).

Cooling of the engine is necessary for the following reasons. The maximum temperature of the cylinder wall is determined by lubricating conditions. After a certain temperature has been reached lubricating conditions begin to deteriorate rapidly, and increased wear, or even seizure of pistons and piston rings, are likely to occur. The maximum permissible temperature depends upon the quality of the lubricating oils; it ranges from 160 °C to 200 °C.

Strength of conventional materials limits the temperature of cylinder heads to approximately 220 °C—260 °C. Cylinder heads of air-cooled engines are usually produced of light alloys whose strength decreases rapidly at temperatures above 200 °C. Additionally, if the temperature of the cylinder head is excessive the inducted air becomes too hot and volumetric efficiency decreases.

If, for instance, the external cylinder wall temperature in an air-cooled engine is 180 °C and the temperature of cooling air 20 °C, the temperature difference is $180 - 20 = 160$ °C. In a water-cooled engine the cylinder is surrounded by 80 °C hot water, and the temperature difference amounts to $100 - 80 = 20$ °C only. As the overall coefficient of heat flow from the cylinder wall into water is favourable, the actual heat transfer is not affected adversely by the decreased temperature difference. Heat transfer from radiator to air is less favourable; here the same conditions prevail as in the case of cylinder fins. However, the temperature difference is only $80 - 20 = 60$ °C. The reduced temperature difference must be compensated by an enlarged cooling surface. Figure 1. gives a diagrammatic illustration of temperature differences in air- and water-cooled engines.

With water-cooled engines the heat transferred from the engine can be distributed over the sufficiently large surface of the radiator, hence the flow of air caused by the movement of the vehicle is adequate for cooling purposes, and it is often possible to dispense with a fan.

When the vehicle is climbing on a steep hill the road speed is reduced, and consequently the quantity of air passing through the radiator is not sufficient to convey the required amount of heat. The quantity of heat carried off by air is less than that conveyed from the engine to the radiator and the difference between both quantities is consumed for heating the cooling water. The temperature difference between radiator and air is thus increased, and accordingly the quantity of heat transmitted to the air is increased also. If at this stage no balance between the heat conveyed to and that taken off the radiator is attained, the temperature of the cooling water rises to boiling point.

To prevent coolant boiling it is necessary to use fans in water-cooled systems, so as to ensure a sufficient velocity of air flowing through the radiator at low speeds during uphill travel.

In modern cars with streamlined bodies the front of the car is lowered and consequently the radiator face reduced. In order to maintain an equal area of the cooling-surface, the depth of the radiator must be increased which means an increased resistance. Direct air flow is not sufficient and the increased

resistance must be overcome by the fan which thus requires a higher power input.

Water cooling can be improved by operating the radiator at overpressure. The boiling point of water is increased and so is the temperature difference between radiator and air. However, due to the higher pressure in the radiator, sealing of joints is more difficult.

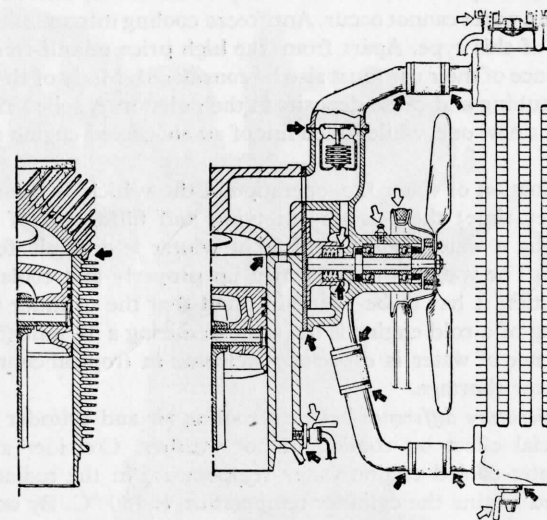


FIG. 1. In air-cooled engines heat is transferred directly to air. Temperature difference is considerable (160 °C approximately). In water-cooled engines heat is transferred first to the water and then from the radiator to air. The temperature gradient is smaller (radiator to air 60 °C). White arrows indicate points requiring maintenance, black arrows possible points of leakage.

The radiator in a water-cooled system, being made of non-ferrous metals, is an expensive component part of the vehicle. It is easily damaged, and, therefore, protected against shocks by flexible mounting. Water cooling requires a water pump whose stuffing boxes are usually not tight enough to prevent leaking, and need attendance. The rubber tubing connecting engine and radiator must permit positional variations and thus presents another source of insufficient tightness. Temperature control requires a thermostat, usually with a by-pass, i.e. with additional tubing and thus a potential source of failures. A fan is needed for air movement. Pressure cooling requires, in addition to the above equipment, a safety valve (in the radiator cap). Deposits of scale in the radiator have an adverse effect on heat transfer and their removal from the radiator is practically impossible; various cleansing agents denude minute fissures and cause leakages. According to statistical

data 20% of all engine failures are caused by faults of the water-cooling system.

A direct air-cooling system is free from this type of deficiency. The main advantages of an air-cooled engine are the following.

No water is required and this means the elimination of 20% of engine failures caused by leakages of radiators, packings, tubing, etc., by faults of thermostats, safety valves, etc. Most important of all, serious breakdowns caused by frozen water cannot occur. Antifreeze cooling mixtures do not prevent all difficulties of this type. Apart from the high price of anti-freeze mixtures the inconvenience of their use must also be considered. Many of these mixtures attack rubber tubing and cause deposits in the radiator. A soiled radiator must be replaced by a new one, while soiled fins of an air-cooled engine can be easily cleaned.

By the elimination of water the operation of the vehicle is facilitated, especially in winter time; there is no emptying and filling up of the cooling system. Running a water-cooled vehicle in winter is difficult for short distance journeys. The water is not warmed up properly and cools off rapidly. In this connection it has to be borne in mind that the cylinder wear during a single starting of a cold engine is the same as during a 31 mile (50 km) journey. The absence of water is especially welcome in tropical countries and in places with water shortage.

Greater temperature difference between cooling air and cylinder has a particularly beneficial effect on cooling in hot weather. Consider a typical instance: in a water-cooled engine water temperature in the radiator is 80 °C, in an air-cooled engine the cylinder temperature is 180 °C. By an increase of the temperature of the surrounding air from 0 °C to 40 °C, the temperature difference in the water-cooled engine is reduced to half of the original value, whereas the drop in the air-cooled engine amounts to only 22%. An air-cooled engine therefore operates satisfactorily under tropical conditions, where water-cooled engines are liable to overheating.

Due to the high average cylinder temperature in the air-cooled engine thermal losses are small; the quantity of heat carried off by the cooling system is less than in the case of water-cooled engines and consequently the thermal efficiency of the air-cooled engine is higher. This explains also the smaller specific fuel consumption. A minimum specific fuel consumption of 0.33 lb/b.h.p.-h (150 g/b.h.p.-h) has been reached with air-cooled Tatra compression-ignition engines.

Less cooling air. Owing to the greater temperature difference one unit of cooling air carries off more heat, and, therefore, less cooling air is required for direct air-cooling of the cylinders than in a water-cooling system. A properly designed air-cooled engine requires only one half of the quantity of cooling air necessary for a water-cooled engine of similar performance. Air channels and ducts have smaller dimensions which is of great advantage particularly in the case of armoured vehicles.

Reduced weight. The manufacture of an air-cooled cylinder requires less

material than that of a cylinder of a water-cooled engine, besides the elimination of radiator, tubing and coolant. These savings mean a reduction of weight and smaller overall dimensions.

Reduced wear of cylinders. The cylinder of an air-cooled engine warms up more rapidly, because it is surrounded by a smaller quantity of material. This has a favourable influence upon the wear of cylinders. Maximum wear occurs

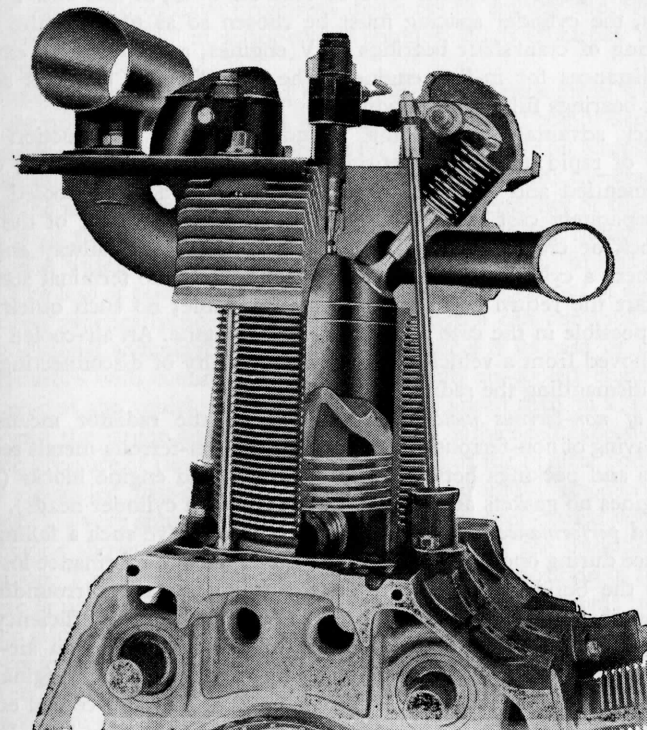


FIG. 2. Single-cylinder element of air-cooled Tatra engines.

immediately after starting, when cylinder walls are cold and inadequate lubrication takes place. Combustion products condensed on the cold cylinder walls attack the bearing surface and cause corrosion particularly in the upper third of the cylinder. This critical period is considerably shortened in an air-cooled engine; an important fact especially for vehicles operated on short runs in towns. Remarkable reduction of cylinder wear has been achieved on engines using producer gas fuel.

Unit cylinder construction. The air-cooled engine design requires a unit cylinder construction. The unit cylinder elements can be advantageously com-

bined into engine units with various numbers of cylinders. Most of the component parts subject to wear are identical for all engines, a circumstance which permits a reduced stock of spare parts. Only crankshafts and camshafts are different. Crankcases, induction and exhaust piping, etc. are not subject to wear and do not appear often as stored spare parts. A unit cylinder construction is shown in Fig. 2.

If one unit cylinder element is to be used for both, in-line and V - types of engines, the cylinder spacing must be chosen so as to allow the proper dimensioning of crankshaft bearings in V engines, and giving no excessive cylinder distances for in-line engines. The use of roller bearings as main crankshaft bearings fulfils this condition.

A further advantage of the unit cylinder built-up construction is the possibility of rapid and less expensive repairs. A damaged cylinder can be singly dismantled and replaced. Similar damage in a water-cooled engine with no separately cast cylinders would call for replacement of the whole engine block or crankcase. An instance of an air-cooled railway engine is known, where a cylinder with piston was replaced at the terminal station in time to start the return run according to time-table; no such quick repair would be possible in the case of a water-cooled engine. An air-cooled engine can be removed from a vehicle without the difficulty of disconnecting water tubing or dismantling the radiator.

Saving of non-ferrous metals. Elimination of the radiator means considerable saving of non-ferrous metals; neither are non-ferrous metals required for gaskets and packings between cylinder heads and engine blocks (in air-cooled engines no gaskets are required for aluminium cylinder heads).

Sustained performance. Air-cooled engines do not give such a falling of in performance during operation as water-cooled engines: performance losses are caused by the build-up of carbon on the cylinder walls surrounding the combustion chamber which means a reduction in volumetric efficiency. The higher mean (not maximum) temperature of the cylinder of an air-cooled engine prevents excessive carbon deposits and thus the original performance of the engine is sustained for a long time. In water-cooled engines, particularly with side-valves, performance losses can amount to 14%. In these engines cooling conditions gradually deteriorate too, because scale is deposited from the cooling water on the walls between cylinder head, cylinder and water jacket.

Though the above advantages of air-cooled engines are significant, it is also necessary to consider their shortcomings. The absence of a water jacket surrounding the cylinders causes increased noise and special attention must be paid to pistons and their clearance in the cylinders. With the varying cylinder temperature valve clearances vary considerably with increase in noise level unless special precautions are taken. Noise inside the vehicle can be reduced by a suitable location of the engine (in the rear) and by proper acoustic insulation.

The use of oil-coolers instead of radiators is sometimes brought forward as

an argument against air-cooled engines. This reproach is not fully justified, because with an increasing specific power output (b.h.p. per unit of displacement) cooling of oil becomes very important. All contemporary water-cooled engines have water jackets along the whole length of the cylinder; formerly this type of design had been repudiated in order to leave the lower part of the cylinder without cooling and so prevent fuel condensation on the cylinder walls and the subsequent thinning of lubricating oil in the crankcase. However, high oil temperatures have prompted designers to employ the overall water jacket type "oil cooler" in water-cooled engines. High efficiency engines require special oil coolers.

A properly designed air-cooled engine operates satisfactorily with a comparatively small oil cooler or even without it. Air-cooled compression-ignition Tatra engines operate smoothly without oil coolers; lower oil temperatures are achieved in these engines by employing roller bearings for the crankshaft.

From the military point of view the reduced vulnerability of the air-cooled engine is of the utmost importance. A bullet hole in the radiator or water tubing of a water-cooled engine means a breakdown due to loss of cooling water. The loss of several fins of the cylinder head or cylinder of an air-cooled engine has practically no ill effects and the engine can continue operation.

An additional advantage of the air-cooled engine is its ease of installation. No difficulties with cooling are encountered with air-cooled engines located in the rear of the vehicle; less cooling air is required than in a water-cooled engine and the larger air pressure head is not influenced excessively by the dynamic pressure of the air in the inlet openings of the vehicle body.

The air-cooled two-cylinder engine with horizontally opposed cylinders (flat twins) is very simple and well balanced. The water-cooled version of the same engine shows a marked disadvantage caused by the complicated water installation. The air-cooled engine is not sensitive to position in the vehicle, for there is no danger of vapour locks forming and subsequent interruption of water circulation.

Air-cooled engines have proved their value also as boat engines, particularly for river craft, where contaminated water causes difficulties in a water cooling system and heat exchangers mean higher cost and increased weight.

2. A survey of the development of air-cooled engines

Air-cooled engines are as old as internal combustion engines. Direct air-cooling was used in the first types of engines. Later on, air cooling was retained for motor-cycle engines and water cooling was generally adopted for car engines. In the first stages of the development of multi-cylinder engines water cooling had been preferred by designers, because water proved to be the proper medium to transfer heat easily from inaccessible parts round the exhaust valve and to prevent local overheating. Designers could, therefore, concentrate their efforts on solution of other problems, e.g. carburation, ignition, lubrication, etc.

Despite such trends air-cooled engines persisted in some automobiles. Franklin, Tatra, Krupp, Phänomen and others are well known firms manufacturing air-cooled vehicle engines for many years. Air-cooled aircraft engines are particularly popular.

Remarkable progress in the development of air-cooled engines was made during the last world war. From the military viewpoint they possess many advantages such as easy servicing, reduced vulnerability, and low weight. Highly appreciated was the built-up (unit cylinder) construction which was responsible for the drastic reduction in the number of spare parts required for large fleets of varying vehicles. At the beginning of the second world war there were several successful vehicles with air-cooled engines in the standard equipment of the German Army, e.g. VW, Phänomen, Krupp, etc. Such vehicles have produced remarkable results in service and all factories concerned were ordered to develop an air-cooled tank engine having a performance of about 750 b.h.p.

The Simmering and MAN engines were among the best developed ones. Both had 16 cylinders. The Simmering engine had an X-type arrangement of cylinders as described on page 450. The cylinders of the MAN engine had a horizontal H arrangement with a calculated total performance of up to 900 b.h.p. Technical data of the engines are given in Table 1.

Technical Data of Air-Cooled Tank Engines

Manufacturer	MAN	Simmering	Continental
Bore, mm	130	135	146.1
Stroke, mm	165	160	146.1
Cylinder, number, arrangement	16 H	16 X	12 V
Displacement, cm ³	35,100	36,800	29,400
Performance, b.h.p.	690	620	750
Speed, rev/min	2,000	2,000	2,400
Weight, kg	1,545	2,250	1,700
Unit performance, b.h.p./l	19.6	16.9	25.5
Mean eff. pressure, kg/cm ²	8.8	7.6	9.55
Mean piston speed, m/s	11	10.7	11.7
Unit weight, kg/b.h.p.	2.24	3.63	2.27

Some vehicle engines of the compression-ignition type were produced during the same period. The considerable experience of the Tatra company which came under German rule after Munich, was directed towards the development of a compression-ignition engine with a cylinder bore of 110 mm and

direct fuel injection. Deutz engines were of the pre-combustion chamber type. Air-cooled engines were also made by Mercedes-Benz, Opel and several other manufacturers.

At that time fighting in North Africa and in Arctic regions increased the usefulness of air-cooled engines.

The advantages of air-cooled engines were recognized by the U.S. Army. Owing to a shortage of powerful vehicle engines, air-cooled Guiberson and Continental radial aero engines were fitted into tanks. The compression-ignition Guiberson engine which had not proved a success in aircraft, gave satisfactory service as a tank engine.

The experience gained from vehicles equipped with air-cooled engines in war service has led to an intensive development in the post-war period. The Deutz factory continued to develop independently the air-cooled chamber engine with 110/140 mm cylinders, i.e. of the same dimensions as the cylinders of their water-cooled engines. Under these conditions it was easy to compare the advantages and short-comings of both types of cooling. The result was significant: air-cooled engines were produced in larger number and production of water-cooled engines ceased almost completely. Air-cooled Deutz engines were followed by other makes, e.g. MWM, Stihl, Porsche, Güldner, in Germany; Petter, Armstrong-Siddeley, SLM, Warchalowski, Continental, Caterpillar, and many more in other countries.

Close attention is also paid to air-cooled engines in the USSR. Many designs were subjected to severe tests under the extreme climatic conditions prevailing on the vast territory of the USSR with results confirming all known advantages of these engines. Today several types of air-cooled petrol and oil engines of original design are being developed and full production is to be expected in the near future.

In the USA a rapid development of air-cooled engines for the U.S. Army was started in the post-war years. Several series, ranging in performance from 0.5 to 1400 b.h.p., were developed. (See description on page 411.) Reduction of the weight of the driving unit and the elimination of cooling difficulties made possible the development of new and more efficient vehicle types. The benefits of standardization is clearly illustrated by the following instance: the smallest series of 6 air-cooled engines containing 800 component parts covers the same range of performance as a series of 78 water-cooled engines containing 23 000 component parts used in World War II. Great efforts are being made towards the application of air-cooled engines for tractors and similar vehicles.

Air-cooled engines have been gradually introduced into passenger cars. New types have appeared following the successful application in the Tatra, VW, and Phänomen cars. Among them were the Citroën 2 CV, Panhard-Dyna, and Porsche. Recently Fiat have brought forward their 500 c.c. which has been followed by its Austrian version of Steyer. To this category belong the BMW Isetta, NSU Prinz, Goliath, Goggomobil and many others. The possibility of using an air-cooled engine in a large car has been demonstrated

by the Tatra T 603 which is equipped with an air-cooled eight-cylinder rear engine developing 100 b.h.p. (Fig. 3.)

However, the introduction of air-cooled engines was not easy. One of the first pioneers was Dr. Eng. H. Ledwinka, former general manager and chief designer of the Tatra automobile works. After he had presented, in 1923, his original design for a popular car with an air-cooled twin-cylinder engine

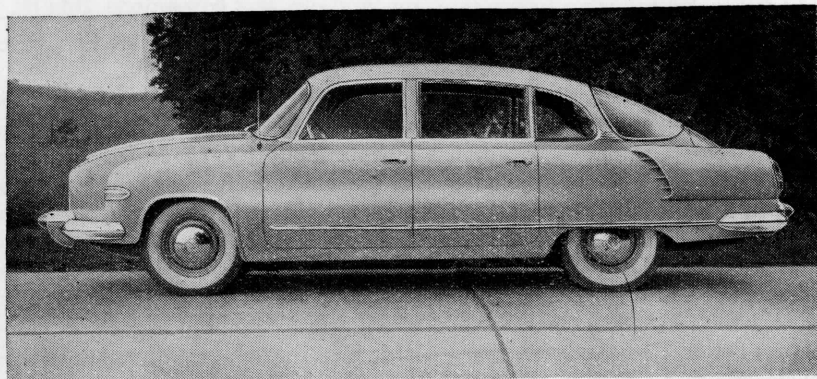


FIG. 3. Tatra 603 car with air-cooled rear engine.

and swinging half-axles, he met a general resentment backed by all important competitors. The hard fight for the first air-cooled car engine was finally decided by the good specifications of the new car which was proved in competitions and races, and was fully accepted by the public. Many of the original Tatras are still running after a total mileage of well over 620,000 miles (1,000,000 km). The first popular car was followed by larger cars, among which the Tatra 87, the pioneer of streamlined bodies, with an air-cooled eight-cylinder 3-litre rear engine, won the greatest fame. The foresight of Dr. Ledwinka determined the line of development of the Tatra works, and the soundness of his ideas has since been proved.

In Germany a similar trend was followed by Dr. Eng. F. Porsche, who built a monument for himself by the design of the renowned Volkswagen. The VW holds the record of the largest production figure among European cars. The air-cooled four-cylinder rear engine contributed largely to the success of this car. Dr. Porsche also called to the public attention other applications of air-cooled engines. He built a series of air-cooled engines for Allgaier tractors and other purposes. The high efficiency and reliability of air-cooled engines has been proved to the world by the remarkable success of the sporting cars designed by Porsche.

Having dealt so far with the general history of the air-cooled engine, let us consider a case of actual development which clearly illustrates the development

from a comparatively simple idea of the past to a complex and highly perfected product of to-day. The author's own experience in designing air-cooled Tatra engines for many years enables him to present a detailed account of development.

The first stage came in 1923. It consisted of a small car with a central supporting tunnel, swinging half-axles and air-cooled two-cylinder engine. The

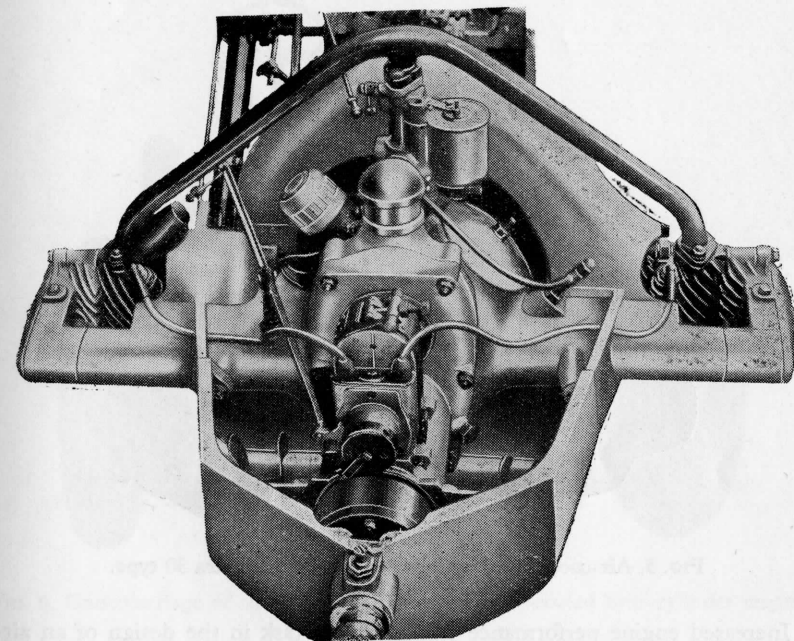


FIG. 4. The air-cooled flat twin engine of the Tatra 12 car was the pioneer of air-cooled motor engines in Czechoslovakia.

quality of the design of this popular car is proved by numerous vehicles of the original type still running after more than 35 years.

Reliability of the first Tatra was largely due to the air-cooled engine forming a part of the frame as shown in Fig. 4. The flat twin had an 82 mm bore, 100 mm stroke, and 1.1-litre displacement, giving a performance of 12 b.h.p. In spite of the solid construction the weight of the vehicle did not exceed 1499 lb (680 kg). The cast iron head and cylinder formed one unit, fitted with fins slanted in the direction of the air stream supplied by a fan. Parallel overhead valves were used.

In 1925 this car won the irksome "Targa Florio" race winning the 1st and 2nd prize in the 1100 c.c. category. In the same year she won the great

Russian Reliability Rally on the 5300 km track Leningrad – Moscow – Tiflis – Moscow, large sections of which consisted of field tracks.

After this experience the Tatra works decided to build air-cooled engines exclusively. They built a flat four-cylinder engine, T 30 with a displacement of 1.68 litres (Fig. 5) and the 1.91 litre type T 52. One of their most popular cars was the 1.16 litre 20 b.h.p. T 57 with an air-cooled four-cylinder engine. The engine had two cylinder blocks. (Fig. 6.)

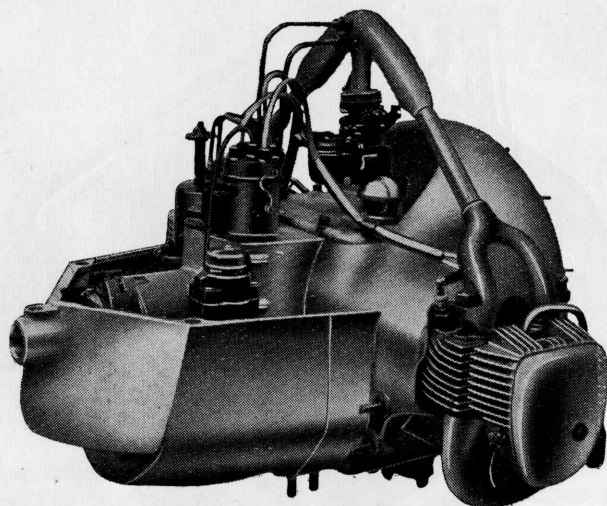


Fig. 5. Air-cooled four-cylinder engine of the Tatra 30 type.

Increased engine performance was the main task in the design of an air-cooled engine intended for a fast passenger car. In 1934 the T 77 appeared as the first version of the fast passenger car with independent suspensions, stream-lined body and an air-cooled eight-cylinder rear engine. The T 77 reached speeds up to 89.9 m.p.h. (145 km/h) with an engine output of only 60 b.h.p. The eight-cylinder V type engine was of 2.97 litres. In the next version of this engine, type T 77a, the cylinder bore was enlarged to 80 mm, and so displacement increased to 3.4 litres and performance to 70 b.h.p. Experience gained from this engine has led to the design of a passenger car known as the type T 87 with an improved version of the original engine giving a performance of 75 b.h.p.

The T 87 represented a further step in development of the air-cooled Tatra engines. Cooling was improved by the application of an aluminium cylinder head with adequately designed fins. The cylinder head was removable, and was of semi-spherical type enabling the use of large valves which guaranteed a high volumetric efficiency. The cooling surface of the cast iron cylin-

der was enlarged by closely spaced fins. The electron metal crankcase was deeply extended underneath the crankshaft axis, and served as a rigid basis of the whole engine. Valves were operated by a camshaft located in the cylinder head. This arrangement prevented valve seat clearance from increasing with temperature and enabled a large valve incline. Cooling air was supplied by two radial fans, one for each line of cylinders.

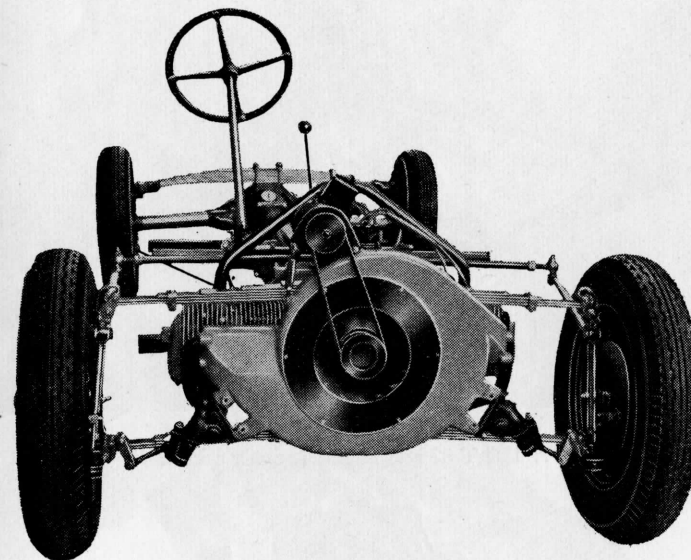


Fig. 6. Undercarriage of the Tatra 57 car with an air-cooled four-cylinder engine.

The modern design was responsible for boosting output to 75 b.h.p., i.e. to 25.3 b.h.p./litre as compared with 18 b.h.p./litre obtained from the original design. The T 87 engine was constructed as a built-up type, i.e. a unit cylinder construction. The four-cylinder flat T 97 type engine was derived from the T 87. It had a unit cylinder construction and was mounted in the rear. Mounting of engines in the rear was made practicable by the small consumption of cooling air. An original feature has been the overhanging engine fixed to the flywheel flange, an arrangement used later on in the mounting of large oil engines (Fig. 8.).

In the following years the Tatra works used their experience with petrol engines to develop a series of air-cooled compression-ignition engines having a bore of 110 mm and a stroke of 130 mm. The best known engine of this type is a twelve-cylinder developing 200 b.h.p. mounted in the Tatra 111 truck. (Fig. 9.).

From the designer's point of view the cylinder head of the T 111 is very

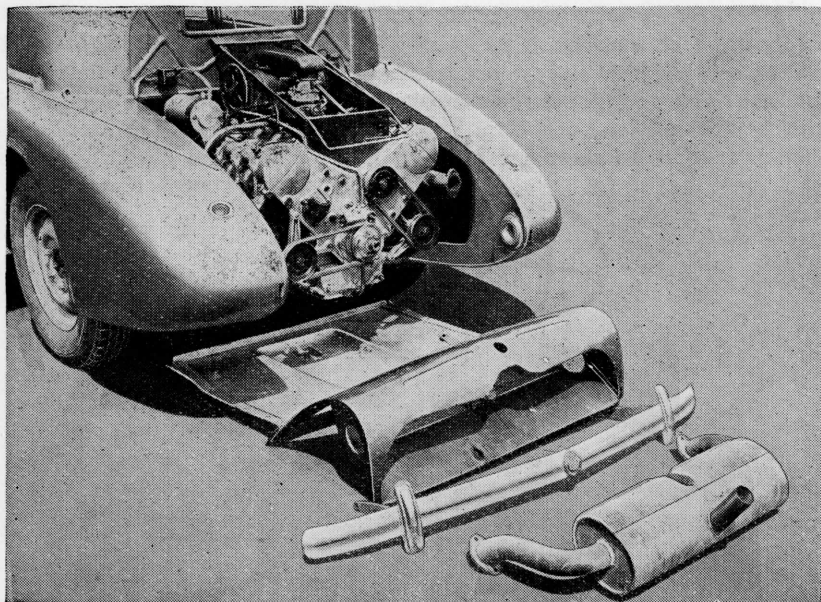


FIG. 7. The T 87 rear engine is easily accessible.

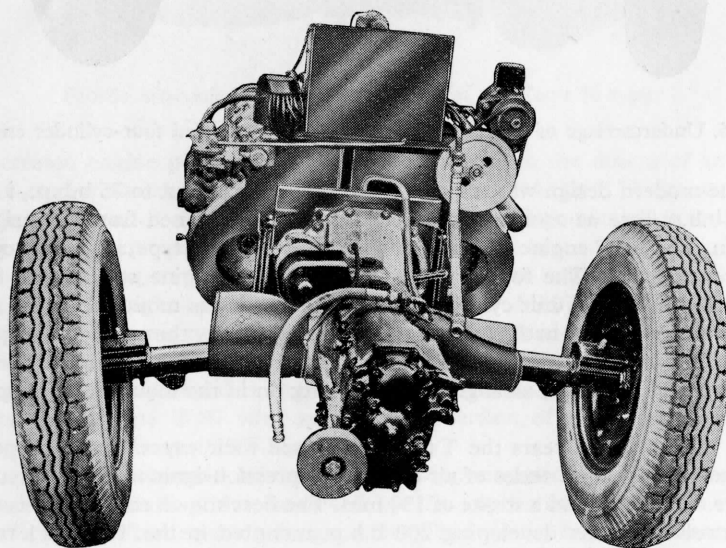


FIG. 8. Driving unit of the T 87 car. Overhung engine on the flywheel flange.



FIG. 9. The ten-ton Tatra 111 is fitted with a twelve-cylinder air-cooled engine.

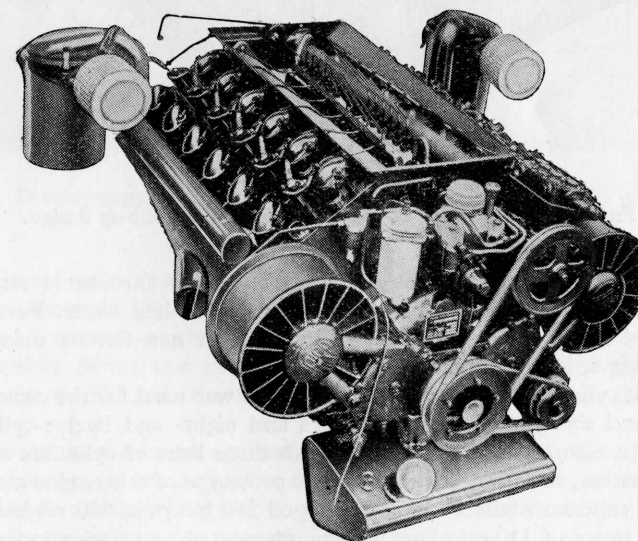


FIG. 10. The twelve-cylinder T 111 engine.

similar to that of the T 87. It has a semi-spherical combustion chamber and the same type of finning. The injection nozzle seated in the cylinder axis did not permit, for reasons of accessibility, operation of valves by a camshaft located

the cylinder head. Therefore, the unusual arrangement of valve operation by two camshafts, mounted in the crankcase, had to be used. Thus, the V type engine contains three camshafts. (Fig. 10.)

The T 111 engine has a cast iron crankcase and a split crankshaft with roller bearings. Giving a performance of 220 b.h.p. the engine weighs 2,173 lb (986 kg) only, i.e. a weight per b.h.p. value of 9 lb/b.h.p. (4.47 kg/b.h.p.).

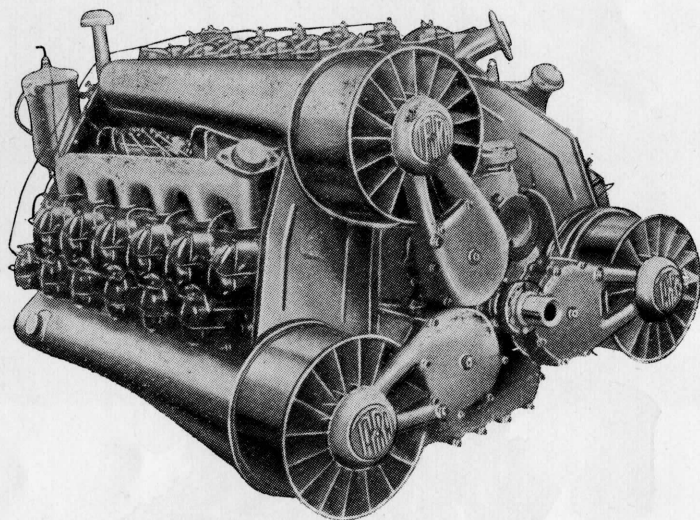


FIG. 11. Air-cooled 18-cylinder W engine of a built-up design.

Compared with water-cooled engines this is a very favourable ratio even without considering the weight of radiator and cooling water. Further advantages of the T 111 were small requirements of non-ferrous metals, and easy starting at low temperature.

The unit cylinder design of this built-up type was used for the construction of four- and six-cylinder in-line engines and eight- and twelve-cylinder V engines. An eighteen-cylinder engine, with three lines of cylinders arranged in W formation, was also constructed. The prototype of this engine assembled and tested experimentally in 1953 developed 330 b.h.p. at 200 rev/min. (Fig. 11.) This series of 110 mm bore was complemented by a five-cylinder in-line engine in 1945.

After 1945 it was decided to enlarge the bore to 120 mm and thus reduce the number of cylinders and improve conditions of combustion. The semi-spherical combustion chamber which proved its value in petrol engines, was not as satisfactory for diesel engines. In order to remove combustion roughness and fumes, the cylinder head had to be redesigned. A toroidal piston face

was used as a combustion chamber and air turbulence in the cylinder brought under control. Before applying the new design in the 120 mm bore series, tests were carried out in the 110 mm bore cylinder.

The good results of the re-designed cylinder head justified its use in the 110 mm bore series, manufacture of which continued due to the necessity to produce spare parts for existing vehicles in the post war years. The develop-

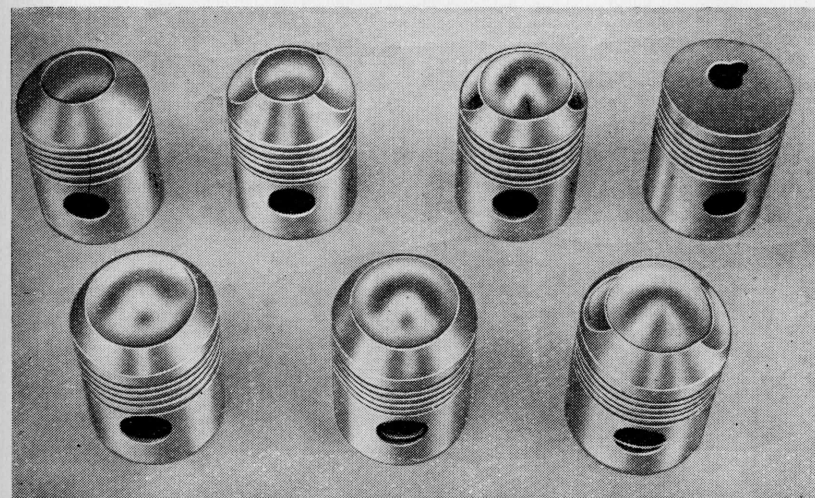


FIG. 12. Development of piston combustion chambers in the Tatra oil engine of 110 mm bore.

ment of combustion chambers with semi-spherical piston faces for Tatra diesel engines is shown in Fig. 12. The re-designed head of the 110 mm bore cylinder produced a smooth combustion, eliminated fumes and reduced specific fuel consumption. Bench test measurements on an eight-cylinder V-type engine indicated a specific fuel consumption of less than 0.33 lb/b.h.p.-h. (150 g/b.h.p.-h).

Following the successful application of air-cooled Tatra engines in passenger cars and trucks, it was decided to use them in the M 131.1 type railroad cars of the Czechoslovak railways. (Fig. 13.) This first example of using air-cooled engines for railway traction was the natural result of the extensive development work carried out by the Tatra works. For the extremely heavy conditions of railway operation, the output of the twelve-cylinder engine was reduced to 160 b.h.p. at 1600 rev/min. and an oil-cooler was fitted.

The air-cooled engine proved its value in the railway service. Breakdowns caused by water freezing were eliminated, traction cars could be laid off at stations without heated sheds, and repairs presented no difficulties. After the

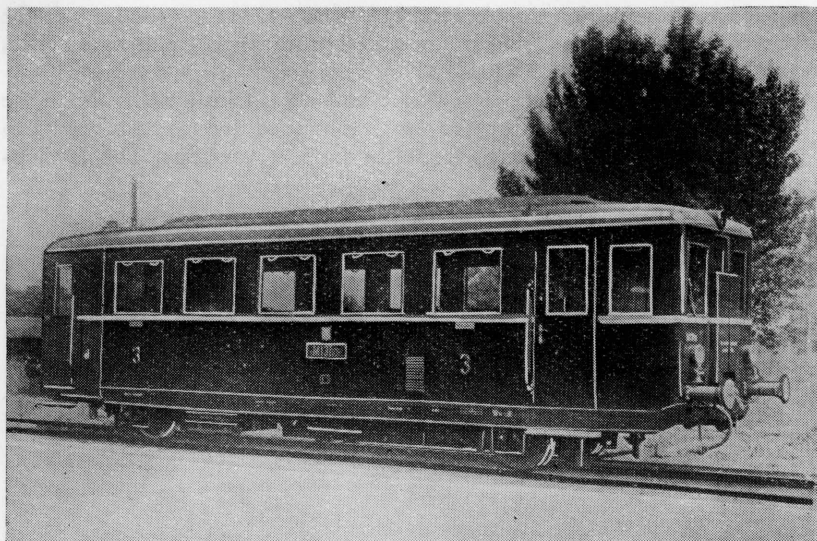


FIG. 13. M 131.1 type Tatra railroad car driven by an air-cooled engine.

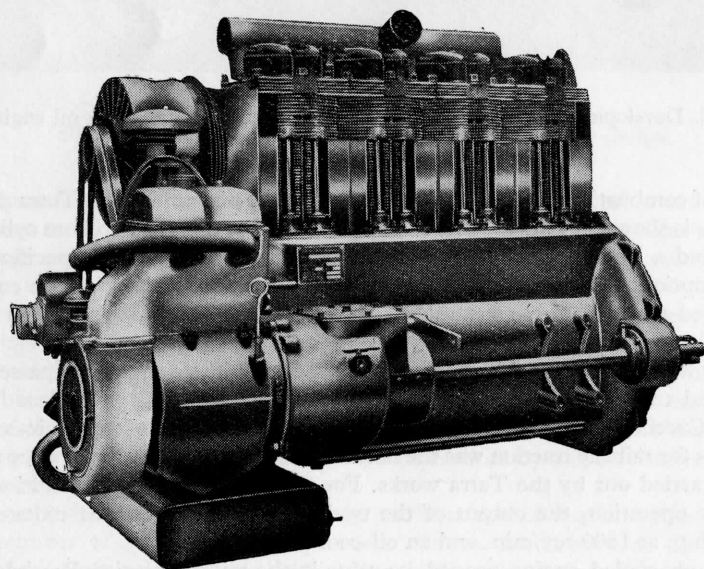


FIG. 14. Four-cylinder T 904 air-cooled engine with two-cylinder petrol engine for starting used in ČKD tractors.

introduction of the redesigned cylinder head, fuel consumption was reduced by 15%. With proper maintenance this railway car with 48 seats consumed 27 litres of oil per 100 km.

The construction of compression-ignition engines of the 120 mm bore series commenced in 1945. A flat six-cylinder intended for a seven-ton truck was the first unit produced. This had a bore 120 mm, stroke 150 mm, output

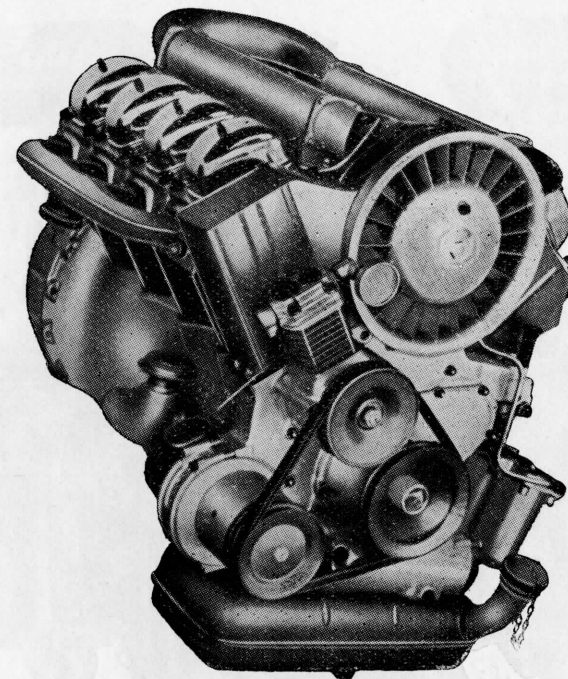


FIG. 15. Eight-cylinder Tatra 928 engine with 120 mm bore and 130 mm stroke.

130 b.h.p. at 2000 rev/min. The four-cylinder in-line type of this series used for the ČKD caterpillar tractor is of interest. The diesel engine is started by means of a two-cylinder petrol engine mounted on its side. No storage battery is needed and the tractor can be readily started even after a standstill of several months. (Fig. 14.)

The new series of the Tatra air-cooled engines (120 mm bore, 130 mm stroke) was exhibited for the first time in 1956. Improvement of specific values and technical simplification were fully incorporated in the development of the new series of compression-ignition engines. Due to consistent standardization the new engines were composed of similar cylinder groups, common crankshaft components, unified fans, oil pumps, etc.

Simplification of design is further illustrated by all in-line and V engines having one type of camshaft and fan. Reduction in number of cylinders due to the enlarged bore, from 110 to 120 mm, made possible a considerable weight reduction. The new eight-cylinder T 928, for instance, developing 180 b.h.p. weighs 1,311 lb (595 kg) as compared with the 2,160 lb (970 kg) weight of the twelve cylinder T 111 having the same output of 180 b.h.p. The

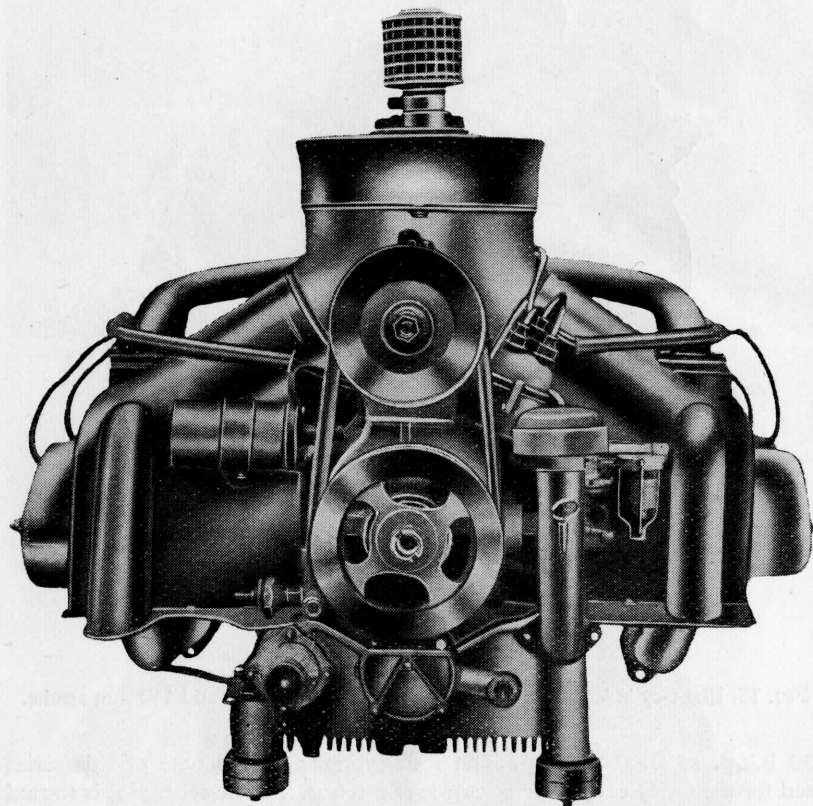


FIG. 16. Engine of the Tatra 111 car with fan on vertical shaft.

weight per b.h.p. value, calculated for 1800 rev/min, was reduced from 11.5 lb/b.h.p. (5.4 kg/b.h.p.) of the Tatra 111 to merely 6.9 lb/p.h.b. (3.3 kg/b.h.p.) of the T 928.

Great care was given to the control of cooling. The fan drive includes a fluid coupling which is not filled with oil until the engine warms up, when a thermostat, placed in the stream of hot air beyond the cylinders, opens

the oil inlet to the coupling. In the cold season fuel consumption is reduced due to less power being required for driving the fan.

Compression-ignition engines are produced with the following numbers of cylinders: 1, 2, 4, 6, 8, and 12. An eight-cylinder engine is shown in Fig. 15. The 8V and 12V types are being developed as supercharged engines which means a further improvement of specific values. Further improvement is

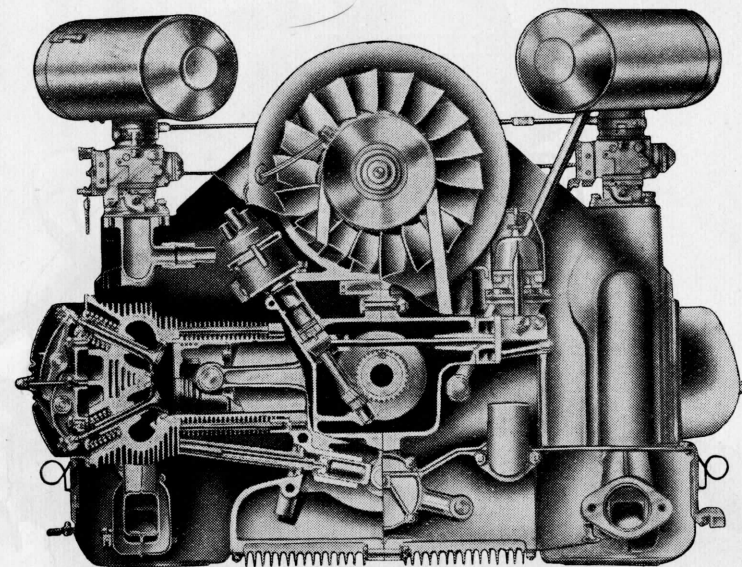


FIG. 17. Cross section of the T 600 engine with fan on horizontal shaft and two carburetors.

possible by developing types with higher speeds. A description of these engines can be found on page 461.

For the post-war Tatra passenger car a flat four-cylinder, with 1.95 litre displacement developing 52 b.h.p. at 4000 rev/min, has been designed. This petrol engine has aluminium cylinder heads and semi-spherical combustion chambers. Valves are not inclined as much as in the T 87, and they are operated by aluminium rods from the camshaft which is placed in the aluminium crankcase. This short-stroke, bore 85 – stroke 86 mm, engine develops 26 b.h.p. per litre which is the same specific output as that of the T 87. Originally the engine had an axial fan with a vertical shaft driven by a bevel gear (Fig. 16.). On the later design a horizontal fan was mounted directly to the dynamo shaft and driven by a V belt. The long manifold piping of the original design was eliminated by using two carburetors and by this arrangement performance was increased to 55 b.h.p. (Fig. 17.).

Despite the results obtained, the fight between followers and opponents of air-cooled engines continued in the post-war years. One of the principal opposing arguments was the firm assertion that a specific output of 26 b.h.p. per litre must be regarded as a maximum and consequently air-cooled en-

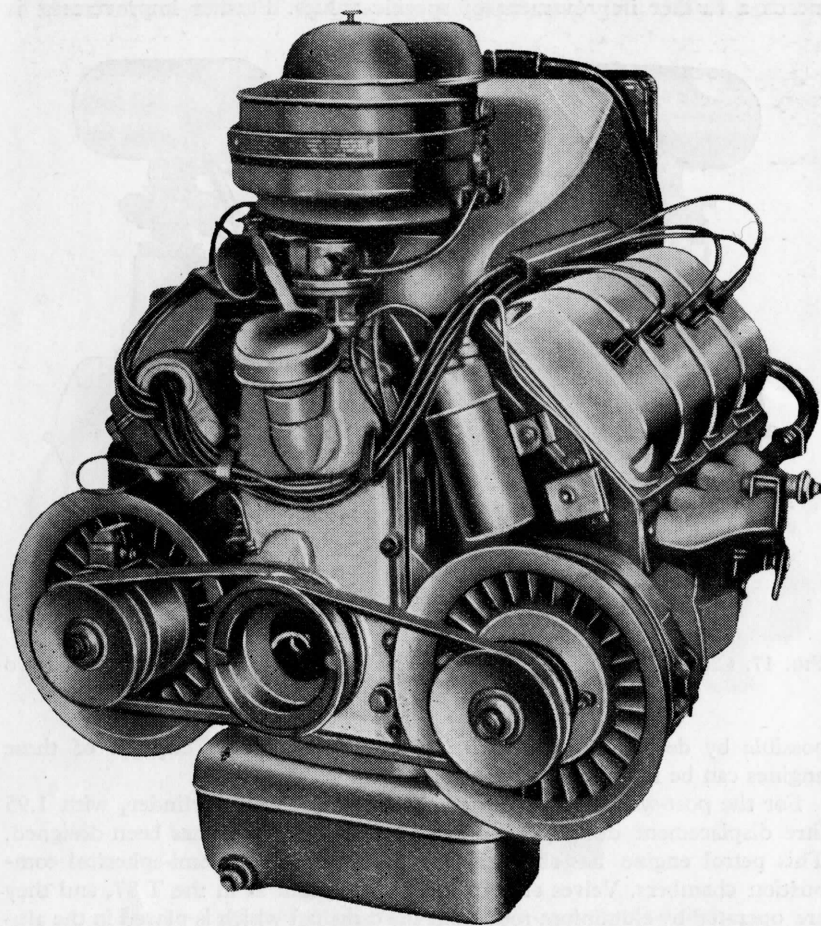


FIG. 18. The eight-cylinder T 603 petrol engine is small, light and efficient. It is fitted in Tatra racing cars.

gines are bound to be inferior to modern water-cooled engines. Further it has been pointed out that in countries with a highly developed automobile industry air-cooled engines are used only on a small scale, particularly in pas-



FIG. 19. Tatra racing car with air-cooled rear engine.

senger cars. The Tatra works decided, therefore, to design a new petrol engine to prove the advantages of an air-cooled engine.

The new Tatra T 603 engine was designed as a special rear engine for passenger cars. Requirements of optimum accessibility, low weight, and of the use of one carburettor with short induction piping necessitated the selection of an eight-cylinder V type engine. Originally cylinder dimensions were 72×72 mm, but the bore was increased to 75 mm at an early stage of development. The combustion chamber was again of a semi-spherical shape. The camshaft at the top of the crankcase enabled the use of a large angle between the valves to give high volumetric efficiency even at high engine speeds. The engine weighs only 330 lb (150 kg) and develops 85 b.h.p. at 4500 rev/min. (Fig. 18.).

The main advantages of an air-cooled engine become apparent by comparing this engine with the T 87. At an equal bore the T 603 has a stroke of only 72 mm and all advantages of a short-stroke engine are provided. Heat losses are smaller and so are the dimensions and the weight of the engine. The total displacement of the engine is 2.545 litres which means a specific output of 33.5 b.h.p./litre, i.e. a value attained by the best types of water-cooled engines. Weight per b.h.p. amounts to 3.2 lb/b.h.p. (1.76 kg/b.h.p.) which is less than corresponding figures of the best mass produced water-cooled engines (if weight of radiator and cooling water are included).

Experience gained from racing car engines is very valuable to designers of air-cooled engines. From the early stages of development up to present times

it has been recognised that more deficiencies can be discovered in a single race than in thousands of miles travelled under normal conditions. Dynamic loads of the valve gear and crank mechanism increase with speed and by increasing rev/min from 4500 to 8000, stresses will increase 3.15 times. An engine having proved its value in a race can be safely assumed to be

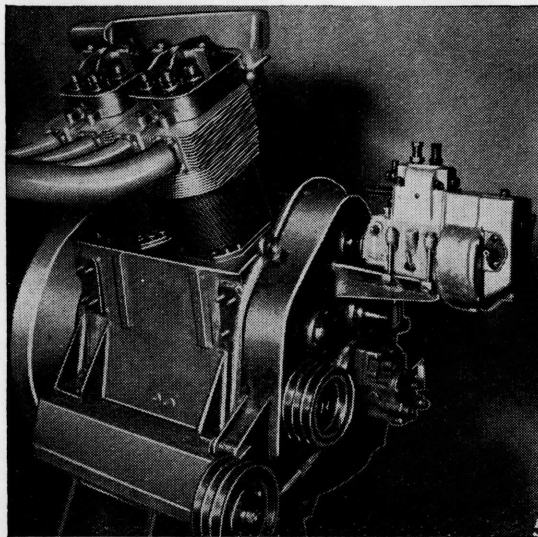


FIG. 20. Experimental twin cylinder Škoda unit, bore 140 mm. Fan and cylinder head cowlings removed.

reliable for running under normal conditions. As a matter of principle the Tatra works used for racing purposes engines selected from normal production series with slight modifications.

The racing type of the T 603 engine differs from the standard engine by having two carburetors, special camshaft and stronger valve springs. Compression ratio is increased from 6 : 1 to 11 : 1 and with special fuel the engine develops 200 b.h.p. at 7500 rev/min. With increasing rev/min this performance will increase even further. (Fig. 19.).

The extensive development work carried out by the Tatra works has been followed by other Czechoslovak factories.

The Škoda works, among others, developed a twelve-cylinder compression-ignition engine having a performance of 450 b.h.p. at 2000 rev/min, bore 140 and stroke 175 mm. An experimental twin cylinder unit of this engine gave very good test results; with an output of 75 b.h.p. at 2000 rev/min specific fuel consumption amounted to about 0.35 lb/b.h.p.-h (160 g/b.h.p.-h.). The prototype cylinder head was fully machined from an aluminium block and, in a hot state, screwed on to the steel cylinder which had turned cooling fins. Two inlet and two exhaust valves were used in each cylinder head, and, between them, in the cylinder axis was the seven-hole injection nozzle for direct fuel injection. A centrifugal cooling fan was mounted sideways (Fig. 20.). After 1945 further development work on this type ceased. The Škoda works also developed several air-cooled flat six-cylinder petrol engines.

The ČKD works successfully used air-cooled four cylinder compression-ignition Tatra T 114 engines for their caterpillar tractors. After this the Tatra

T 904 engine (bore 120 mm), with a small two-cylinder starting petrol engine, was used in a larger caterpillar tractor of the same company. In view of the excellent performance of air-cooled Tatra engines in tractors, the ČKD works embarked on the development of an air-cooled compression-ignition engine of their own. Following the first tests with a 145 mm bore ex-

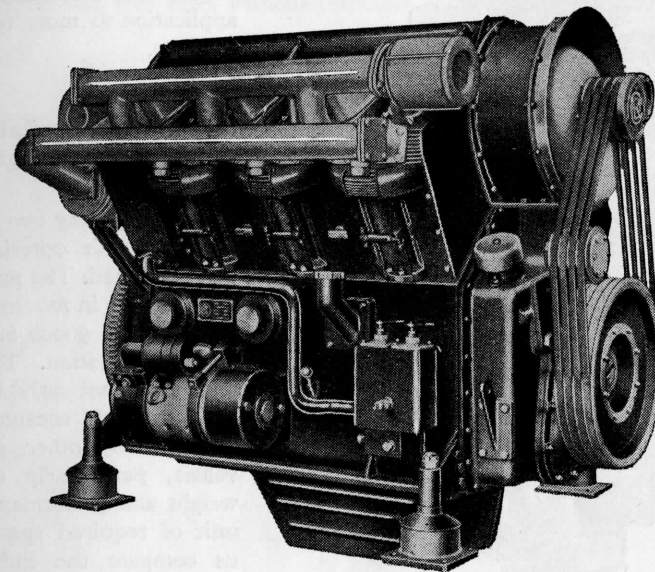


FIG. 21. Air-cooled six-cylinder ČKD V engine, bore 145 mm, for heavy duty service.

perimental single-cylinder unit, tests were carried out with variously shaped combustion chambers and four- and two-valve cylinder heads. The result was a two-valve aluminium cylinder head fixed by a flange joint to the steel cylinder having turned fins. The first engine of this type was a six-cylinder with two banks of cylinders arranged in a V inclined at 60°. (Fig. 21). The engine, having a performance of 160 b.h.p., is being developed further. The ČKD production program includes a twelve-cylinder engine.

Simultaneously developed motor-cycle engines gained a reputation based on quality and high performances. Four- and two-stroke JAWA engines lead the field with the Strakonice ČZ engines as second.

Among air-cooled aircraft engines developed in Czechoslovakia it is worthwhile to mention the remarkable design of the two-stroke compression-ignition ZOD type produced by the Zbrojovka in Brno (Fig. 22). Former manufacturers of air-cooled aircraft engines were Walter, Avia, ČKD, etc.

Today, the tendency to use air-cooled engines for stationary installations can be observed all over the world. Modest requirements of maintenance and

insensitiveness towards climatic conditions are mainly responsible for this trend. Similar properties are required for tractor and popular car engines.

The rapid development is bound to bring about a further refinement of air-cooled engines and their subsequent application to more types of vehicles.

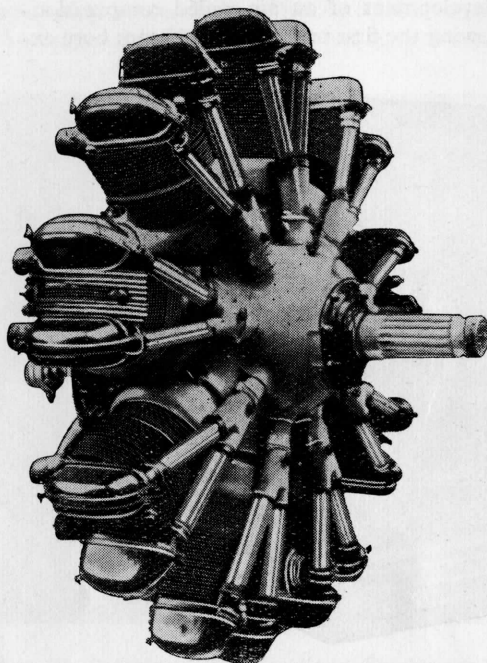


FIG. 22. Air-cooled two-stroke aircraft engine of the ZOD type.

3. Comparison of air- and water-cooled engines

For comparing two engine types, suitable criteria must be established. The principal requirement in movement of persons and goods is economical operation. This is influenced not only by the specific fuel consumption, but also by other specific values, particularly specific weight and performance per unit of required space. Let us compare the individual characteristics of vehicle engines.

1. *Fuel consumption* is of utmost importance, because it has a direct bearing upon transport costs. Specific fuel consumption serves as an important comparative value and also expresses the overall efficiency of an engine. Type of fuel and its price have to be considered, too. At equal specific fuel consumption a diesel-engine is more economical than a petrol engine.

Fuel consumption for passenger cars and for trucks is even more important. This consumption is determined not by the engine only, but by the overall properties of the vehicle as well. A well designed vehicle may compensate for the shortcomings caused by a less economical engine.

2. *Weight of engine* is another important property. Vehicles are built to transport persons and goods; therefore, the weight of the vehicle must be kept at a minimum. It has to be borne in mind that the engine weight determines, to some extent, the weight of other parts of the vehicle. A low-speed engine with a large torque requires heavier transmission and driving gear. Increased dead weight means higher fuel consumption and greater wear of tyres. Engine weight can be reduced in cars and buses by using light metals for compo-

nent parts; this, however, is less feasible for truck engines. Specific weight is a further comparative value. In water-cooled engines the weight of radiator and cooling water should be added to the weight of the engine unit.

3. *Engine dimensions* ought to be as small as possible. A small engine can be easily accommodated in a passenger car, and its weight can be distributed between front and rear axles without difficulty. The overall length of buses is

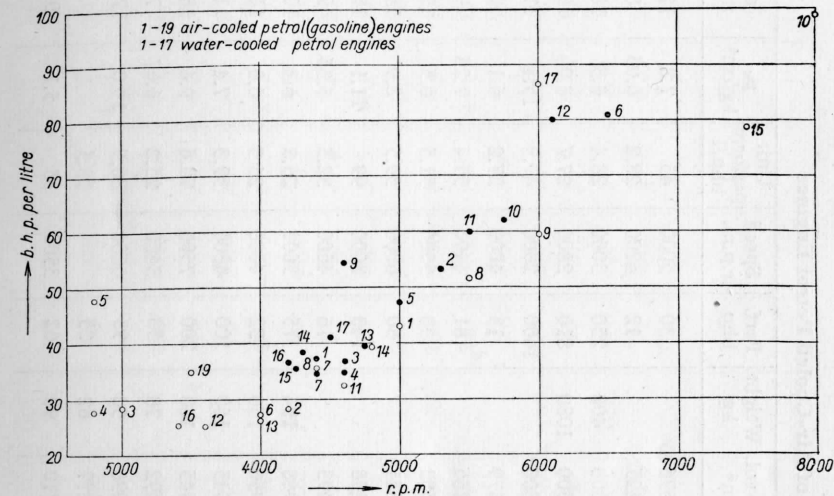


FIG. 23. Unit performance of petrol engines.

○ — air-cooled engines, ● — water-cooled engines, 5 — supercharged engines.

limited and the largest possible space must be made available for passengers. A small engine, located beside the driver's seat or beneath the floor, may increase the capacity of the vehicle by several seats. The same considerations apply to the utilization of the length of trucks for loadings area.

4. *Maintenance* is an important factor in overall transport costs. In addition to direct maintenance cost, the value of idle standstill time has to be calculated. Often the duration of standstill depends on the availability of spare parts. Sometimes one single spare part missing may cause the vehicle to be out of operation for a long time.

The above factors must be considered whenever engines are being compared. Performance per unit displacement is less important for comparison unless it is considered instead of another specific value, or in cases where displacement is used as a basis for taxation or determining racing categories. An increased specific performance means an improvement of other specific values. Performance per unit displacement depends largely on the rev/min value.

Engine speed can be advantageously increased up to a corresponding mean

Technical Data of Air-Cooled Petrol Engines

	Manufacturer	Bore mm	Stroke mm	Cyl.	Sw. vol. cm ³	Weight kg	Perf. bhp	Speed r.p.m.	Unit perform bhp/l	p_e kg/cm ²	c_m m/s	Unit weight kg/bhp	Comp. ratio
1	BMW 700	78	73	2F	696		30	5000	43	7.8	12.3		7.5
2	Citroën	66	62	2F	425		12	4200	28.2	6.05	8.7		6.25
3	Continental	117.5	101.6	8F	8808	408	250	3000	28.4	8.5	10.1	1.64	
4	Continental	146.1	146.1	12V	29300	1080	810	2800	27.7	8.9	13.6	1.34	
5	Continental	146.1	146.1	12V	29300		1400	2800	47.9	15.4	13.6		
6	Fiat 500	66	70	2L	479		13	4000	27.2	6.1	9.35		6.5
7	Chevrolet	85.7	66	6F	2286		81	4400	35.4	7.25	9.7		8.0
8	NSU Prinz	75	66	2F	583		30	5500	51.5	8.5	12.1		6.8
9	Panhard Dyna	85	75	2F	841		50	6000	59.5	8.9	15.-		
10	Porsche RSK	85	66	4F	1498		148	8000	99	11.1	17.6		9.8
11	Steyer Puch	70	64	2F	493		16	4600	32.5	6.35	9.8		
12	Tatra 87	75	84	8V	2968	194	75	3600	25.2	6.3	10.-	2.59	5.6
13	Tatra 600	85	86	4F	1950	150	52	4000	26.5	6.0	11.5	2.88	6.0
14	Tatra 603	75	72	8V	2545	160	100	4800	39.3	7.4	11.5	1.6	6.2
15	Tatra 603 Sport	75	72	8V	2545	160	200	7500	78.6	9.4	18.0	0.8	12.-
16	Volkswagen	77	64	4F	1192	78	30	3400	25.2	6.67	7.24	2.6	6.6
17	JAP	84	99	2V	1096	50	95	6000	86.5	13.0	19.7	0.6	14.-
18	Willys	69.85	57.15	4F	877	62	25		28.5			2.48	6.5
19	American Motors	82.5	82.5	4V	1770	90	62	3500	35	5.1	9.65	1.45	7.5

Table 2. cont.

1	Austin 55	73	88.9	4L	1489		56	4400	37.6	7.7	13		8.3
2	Alfa Romeo 2000	84.5	88	4L	1975		105	5300	53.2	9.-	15.5		8.25
3	Čajka	92	92	8V	4890		180	4600	36.8	7.2	12.6		
4	Fiat 600	60	56	4L	633	71.4	22	4600	34.8	6.8	8.6	3.24	7.5
5	Fiat 1800	72	73.5	6L	1795		85	5000	47.3	8.5	12.3		8.8
6	Ferrari 410	88	68	12V	4962		400	6500	80.7	11.2	14.7		9.0
7	Ford Zephyr	82.5	79.5	6L	2552	196	90	4400	35.3	7.2	11.7	2.18	7.8
8	Hillman Minx	76.2	76.2	4L	1390		52	4400	37.4	7.65	11.16		8.0
9	Chrysler LC3H	101.6	99	8V	6423		350	4600	54.5	10.6	15.2		10.0
10	Jaguar	83	106	6L	3442		213	5750	62	9.7	20.3		8.0
11	Mercedes Benz 300	85	88	6L	2996	256	180	5500	60	9.8	16.1	1.42	8.55
12	Mercedes Benz 300 SL	85	88	6L	2996		240	6100	80	11.8	17.9		9.5
13	Morris 1000	62.9	76	4L	948		37.5	4750	39.6	7.5	12.0		8.3
14	Opel Kapitän	85	76.5	6L	2605		100	4300	38.4	8.03	10.95		7.8
15	Renault Dauphine	58	80	4L	845		30	4250	35.5	7.52	11.3		7.25
16	Škoda 440	68	75	4L	1089	103	40	4200	36.75	7.88	10.5	2.57	7.0
17	Triumph Herald	63	76	4L	948		39	4500	41.1	8.25	11.4		8.0

Cylinder arrangement: V, L in-line, F flat.

piston velocity of 29 to 36 ft/s (9 to 11 m/s). Mean piston velocities in engines of passenger cars reach values up to 50 ft/s (15 m/s) and even more. In such cases, however, the risk of a considerable reduction of the mechanical efficiency of the engine occurs. Low mean piston velocities have an adverse effect upon the lb/b.h.p. (kg/b.h.p.) weight of the engine. In some cases, however, optimum conditions can be attained at smaller mean piston velocities; especially in robustly built engines where the accelerating forces of the heavy pistons and connecting rods cause a reduction of the mechanical efficiency even at low speeds. Specific fuel consumption increases with reduced mechanical efficiency, and, therefore, speeds of compression-ignition engines are kept at 1800 rev/min or less. The economic advantage of higher mechanical efficiency is partially counterbalanced by a higher specific weight.

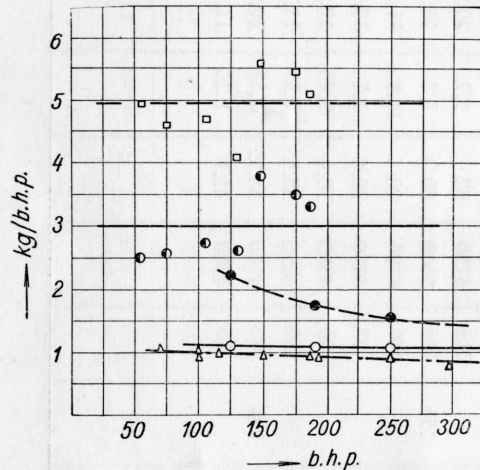


FIG. 24. Comparison of weights in kg/b.h.p.

□ — weight of water-cooled engines with accessories for lorries and buses, ● — basic weight of engines for lorries and buses, ● — weight of air-cooled vehicle engines with accessories, ○ — basic weight of air-cooled vehicle engines, △ — basic weight of air-cooled aircraft engines.

the best known vehicle engines are given in Table 2. Specific performances of engines listed in Table 2 are shown in the diagram Fig. 23 where the full lines indicate maximum engine performances attainable without the use of superchargers. [58]. Mean effective pressures are also shown in the diagram.

The benefit of smaller weight is even more marked in the case of large size air-cooled petrol engines. The Continental Company converted many of their aircraft engines into large size petrol engines suitable for buses and trucks. Weights of these engines approach very closely those of aircraft engines. Fig. 24 shows weights of these engines, net and including accessories, compared with weights of water-cooled engines. It is clearly illustrated that air-cooled engines weigh approximately only 1/3 of the weight of water-cooled engines.

Compression-ignition engines. Similar considerations apply to this type of engine. Technical data of proved compression-ignition engines are given in Table 3 and Fig. 25. Table 4 contains data of two-stroke and supercharged engines including dimensions and enables, therefore, a more complete compar-

petrol engines. When comparing air-cooled and water-cooled engines it must be remembered that the weight of water-cooled engines is given in tables without the weight of radiators and cooling water. Technical data of

Table 3. Technical Data of Air-Cooled Oil Engines

	Manufacturer	Bore mm	Stroke mm	Cylind	Sw. vol. cm ³	Perf. bhp	Speed r.p.m.	Unit perfom bhp/l	P _e kg/cm ²	c _m m/s	Weight kg	Unit weight kg/bhp
1	Continental	146.1	146.1	12V	29400	750	2400	25.5	9.55	11.7	1700	2.27
2	ČKD	145	180	6V	17800	160	1600	9.0	5.05	9.6	1300	8.1
3	Deutz F 4L 514	110	140	4L	5300	90	2300	17.0	6.68	11.8	476	5.38
4	Deutz F 6L 514	110	140	6L	8000	130	2250	16.25	6.40	10.58	625	4.80
5	Deutz F 8L 614	110	140	8V	10640	175	2250	16.50	6.68	10.58	850	4.85
6	Deutz F 6L 612	90	120	6L	4580	84	2800	18.3	5.9	11.2	360	4.3
7	Guiberson	130	150	9R	16730	250	2200	15.0	6.15	10.25	290	1.15
8	MAN	130	165	16H	35100	690	2000	19.6	8.8	11.0	1545	2.24
9	MWM	105	120	8V	8312	140	2500	16.9	6.1	10.0		
10	Paxman	152.4	167.6	12V	3650	446	2100	12.8	5.5	11.7	228	11.35
11	Petters	76.2	76.2	4L	1390	20	3000	14.4	4.32	7.6	255	28.0
12	Petters	80	110	2L	1106	9	1500	8.1	4.9	5.5	355	6.8
13	Robur GD4	90	125	4L	3180	52	2600	16.3	5.6	10.8	550	3.7
14	Robur LD8	100	125	8V	7850	150	2600	19.1	6.6	10.8		
15	SLM	110	140	12F	16080	220	2000	13.70	6.16	9.3		
16	SLM	110	140	8F	10600	150	2000	14.0	5.75	10.3		
17	Simmering	135	160	16X	36800	620	2000	16.9	7.6	10.7	2250	3.63
18	Tatra 111	110	130	12V	14820	200	2000	13.50	6.05	8.7	986	4.93
19	Tatra 928	120	130	8V	11752	180	2000	15.3	6.9	8.7	595	3.3
20	Tatra 928K	120	130	8V	11752	220	2000	18.7	8.4	8.7	630	2.85

ison. The most important values are performance per unit of required space in b.h.p./ft³ (b.h.p./m³) and specific weight in lb/b.h.p. (kg/b.h.p.) Other values, with the exception of specific fuel consumption and life, are less important from the consumer's point of view.

Air-cooled compression-ignition engines, compared with water-cooled, are conspicuous once again by low specific weight and high performance per unit

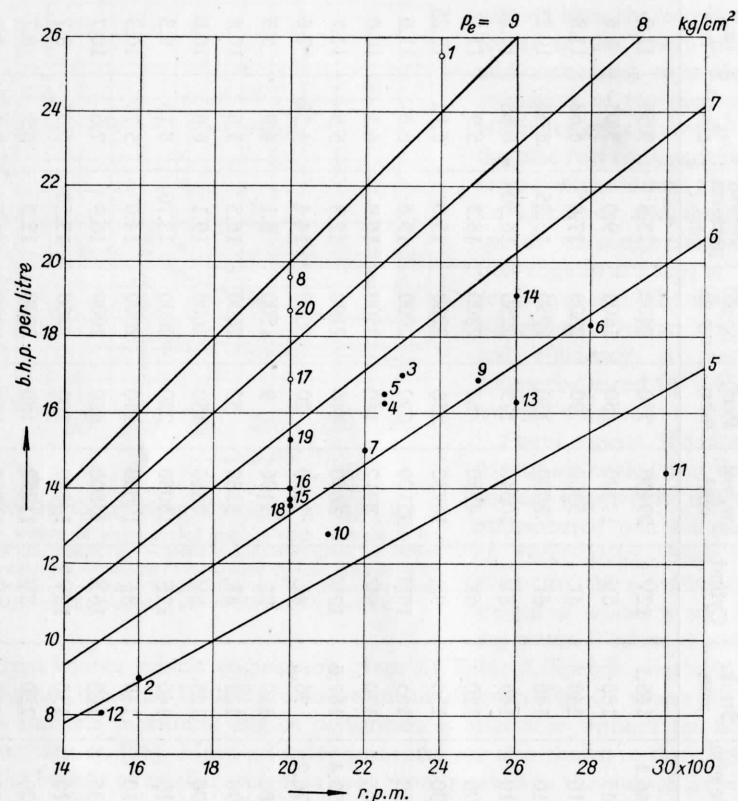


FIG. 25. Unit performance and mean effective pressure of air-cooled compression-ignition engines.

of required space. The benefit of high rev/min is demonstrated in the case of the Hercules engine having a performance of 6.1 b.h.p. per ft³ (215 b.h.p. per 1 m³) of space and a specific weight of 7.5 lb/b.h.p. (3.85 kg per b.h.p.) The corresponding values would be still better in an air-cooled engine having the same speed.

Good specific values can be attained with supercharged engines. The same possibility exists with air-cooled engines. It is apparent from the table of technical data that air-cooled engines without superchargers are closely approaching values of supercharged water-cooled engines. A remarkable

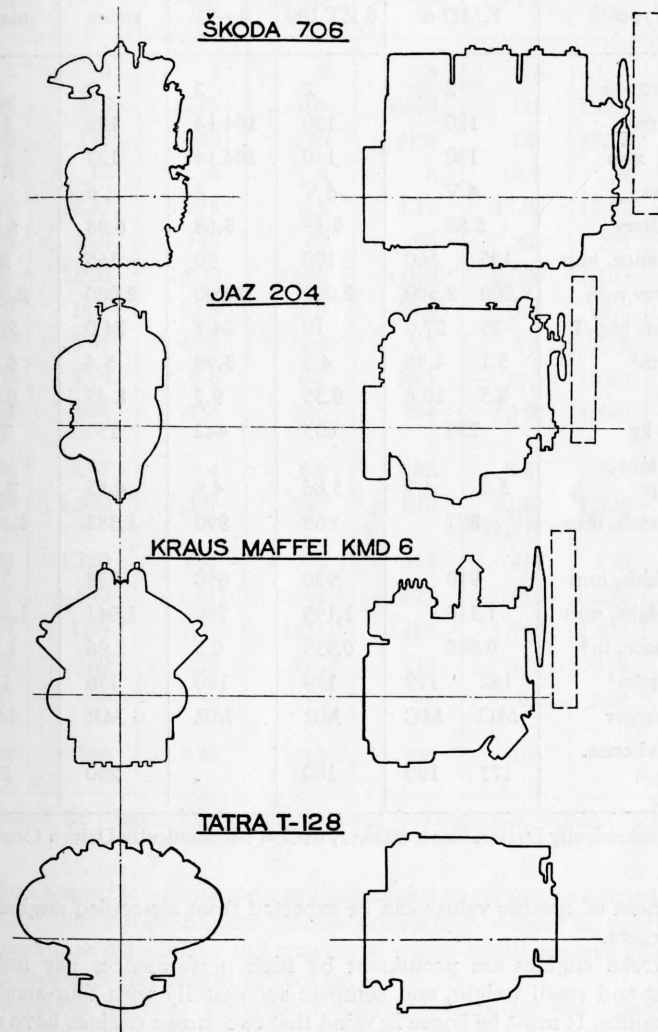


FIG. 26. Comparison of engine size.

Škoda 706 — water-cooled four-stroke, JAZ 204 — water-cooled two-stroke, Krauss-Maffei KMD 6 — water-cooled two-stroke, Tatra T-128 — air-cooled four-stroke

Comparative Table of

Manufacturer	Krauss-Maffei	Gräf & Stift	G. M.	JAZ 206	JAZ 206
Type	KMD 6	6 ZT 180	4-51	series	max.
2- or 4-stroke	2	2	2	2	2
Bore, mm	120	120	104.14	108	108
Stroke, mm	130	140	104.14	127	127
Cylinders	4 V	6 V	4	6	6
Displ., litres	5.88	9.49	3.68	6.98	6.98
Performance, bhp	145 160	180	90	165	200
Speed, rev/min	2,200 2,500	2,000	2,800	2,000	2,000
Unit perf. bhp/l	25 27.6	19	24.7	24.0	28.7
p_e , kg/cm ²	5.1 4.96	4.3	3.98	5.4	6.45
c_m , m/s	9.5 10.8	9.35	9.7	8.45	8.45
Weight, kg	735	695	442	750	750
Unit weight, kg/bhp	5.2 4.7	3.86	4.9	4.55	3.75
Max. length, mm	887	865	990	1,383	1,383
Max. width, mm	910	920	650	738	738
Max. height, mm	1,110	1,195	780	1,041	1,041
Total space, m ³	0.895	0.955	0.5	1.06	1.06
Perf. bhp/m ³	162 179	189	180	156	188
Supercharger	MC MC	MR	MR	MR	MR
Spec. fuel cons. g/bhp h	177 190	180	.	230	230

MR = Mechanically Driven Roots Blower, MC = Mechanically Driven Centrifugal

improvement of specific values can be expected from air-cooled engines with superchargers.

Two-stroke engines are prominent by high performances per unit displacement and small weight, and compete successfully with four-stroke air-cooled engines. It must be borne in mind that two-stroke engines have double the number of power strokes and are partially supercharged. The charging pressure is not high, but it is always higher than back pressure of the exhaust gases.

Oil Engines for Motor-Cars

Table 4a

FO-DEN	Tatra	Škoda	Praga	Hercules	Saurer	Cummins	Soviet Diesel
FD-6	111	706	RND	DIX 60	CVDL	NHS 600	W2
2	4	4	4	4	4	4	4
85	110	125	105	92.08	110	130.2	150
120	130	160	130	101.6	140	152.4	180
6	12	6	4	6	12 V	6	12 V
4.09	14.82	11.78	4.5	4.11	15.96	12.12	38.86
126	220	145	60	92	300	275	500
2,000	2,250	1,800	2,000	3,000	2,200	2,100	1,800
30.8	14.9	12.3	13.3	22.3	18.8	22.7	12.8
6.9	5.96	6.15	6.0	6.7	7.7	9.75	6.45
8.0	9.75	9.6	8.7	10.1	10.3	10.65	11.2
499	986	930	415	354	1,150	1,590	750
3.95	4.47	6.4	6.9	3.85	3.83	5.8	1.5
1,280	1,332	1,387	990	970	2,082 (1,778)	1,526	1,558
740	1,150	662	575	535	914	823	1,116
990	840	1,167	1,010	825	914	1,229	1,072
0.94	1.25	1.07	0.575	0.427	1.740	1.545	1.87
134	160	135	104	215	172	178	267
MR	—	—	—	—	Bü	MR	—
184	180	190	212	200	165	.	180

Compressor, Bü = Büchi Turbo-Compressor, () = Dimension without Fan or Büchi.

As far as specific weight and required engine space are concerned standard air-cooled four-stroke engines exhibit satisfactory values. It should be remembered that dimensions and weights of water-cooled engines listed do not include radiators and weight of coolant.

Dimensional sketches of engines having approximately equal performances are shown in Fig. 26: Škoda 706, JAZ 204, Krauss Maffei KMD6 and Tatra T 128. All radiators are drawn in a smaller scale than engines. It is apparent, that air-cooled engines are the shortest; their overall width is increased by the

Various Two- and

Manufacturer	Cummins	Mercedes Benz	MAN	Mercedes Benz	D. B.	D. B.
Type	JSX	OM 636	—	MB 507	MB 820 Aa	MB 820 Abs
2- or 4-stroke	4	4	4	4	4	4
Application	racing	passenger car	tank	tank	railway	railway
Bore, mm	104.8	75	130	158	172	172
Stroke, mm	127.0	100	165	180	205	205
Cylinders	6	4	16H	12 V	12 V	12 V
Displ., litres	6.54	1.77	35.1	42.2	57.0	57.0
Performance, bhp	345	40	690	720	860	1,000
Speed, rev/min	4,000	3,200	2,000	2,000	1,500	1,500
Unit perf., bhp/litre	52.9	22.6	19.7	17.0	15.1	17.5
p_e , kg/cm ²	11.9	6.32	8.85	7.7	9.05	10.5
c_m , m/s	17.0	10.7	11.0	12.0	10.25	10.25
Weight, kg	380	190	1,545	900	2,400	2,700
Unit w., kg/bhp	1.1	4.83	2.24	1.25	2.79	2.70
Supercharger	MR	—	—	—	MC	Bü
Cooling	water	water	air	water	water	water

MR = Mechanically Driven Roots Blower, Bü = Büchi Turbo-Compressor,

fans located sideways. From the assembling point of view the length is the decisive dimension of the engine, its width is less important. As a point of interest, the air-cooled eight-cylinder Tatra V engine is shorter than the four-cylinder two-stroke Krauss-Maffei engine with radiator. The Tatra T 128 engine is also of an older design.

Interesting conclusions can be drawn from comparing the dimensions of the two-stroke GM6-71 engine with air-cooled Tatra T 111 and T 603 types and with the Rover and Boeing gas turbines. Technical data of all types concerned are given in Table 5. Gas turbines are significant for their small dimensions and weights; they have, however, a high specific fuel consumption. One-stage rotary compressors will be used as a rule in gas turbines for automotive purposes. This will mean a pressure ratio of 3.5:1 and consequently a low thermal efficiency as in all small size turbines and compressors. Specific

Four-Stroke Oil Engines

Table 4b

Fairbanks	G. M.	Eng. Electric	Maybach	D. B.	Guiberson	Junkers	ZOD
38 D 8 1/8	12-278	16 SVT	MD 650	MB 502	T 1020	Jumo 205	—
2	2	4	4	4	4	2	2
railway	railway	railway	railway	tank	tank	aircraft	aircraft
206.4	222	254	185	175	130	105	120
2 × 254	267	305.8	200	230	140	2 × 160	130
10	12 V	16 V	12 V	16 V	9 Radial	6	9 Radial
170	125	246	64.5	88.46	16.74	16.62	13.32
2,000	1,200	1,800	1,200	1,330	265	600	260
810	750	750	1,600	1,650	2,260	2,200	1,560
11.7	9.6	7.35	18.6	15.0	15.8	36.0	19.6
6.53	5.77	8.8	10.45	8.2	6.3	7.4	5.64
6.85	6.7	7.65	10.65	12.6	10.55	11.7	6.9
14,900	10,880	15,870	3,600	1,870	290	520	321
7.45	9.0	8.8	3.0	1.41	1.1	0.87	1.23
MR	MR	Bü	Bü	—	—	MC	MC
water	water	water	water	water	air	water	air

MC = Mechanically Driven Centrifugal Compressor.

fuel consumption can be lowered by using an efficient heat exchanger. However, heat exchangers have large dimensions and so the advantage of small overall dimensions of the gas turbine would be lost.

The Boeing gas turbine has no heat exchanger. The Rover gas turbine uses a partial heat exchanger, and the overall dimensions of the unit are larger. Dimensions are shown in Fig. 27. By comparing the weights and specific fuel consumption given in Table 5, it can be seen that the use of gas turbines for passenger cars is not as advantageous as it seemed at first sight.

The automobile of the future must be lighter and more economical. Air-cooled engines have all properties to fulfil the requirements of future designs and therefore, it may be expected that the general application of air-cooled engines in aircraft and motor-cycles will be followed by their use in automobiles, too.

Table 5

Comparative Data of Engines shown in Fig. 27.

	Boeing	Rover	Tatra 603	Tatra 111	GM 6-71
Normal perf. bhp	—	150	100	195	165
at rev/min	—	—	4,800	2,000	2,000
Maximum perf., bhp	175	200	200	220	200
at rev/min	36,000	40,000	7,500	2,250	2,000
Total weight, kg	90.7	204	160	986	750
Compression ratio	2.88 : 1	3.5 : 1	12 : 1	17 : 1	16 : 1
Spec. fuel cons. g/bhp h	670	537	250	175	230
Unit weight kg/bhp	0.52	1.02	0.80	4.47	3.75

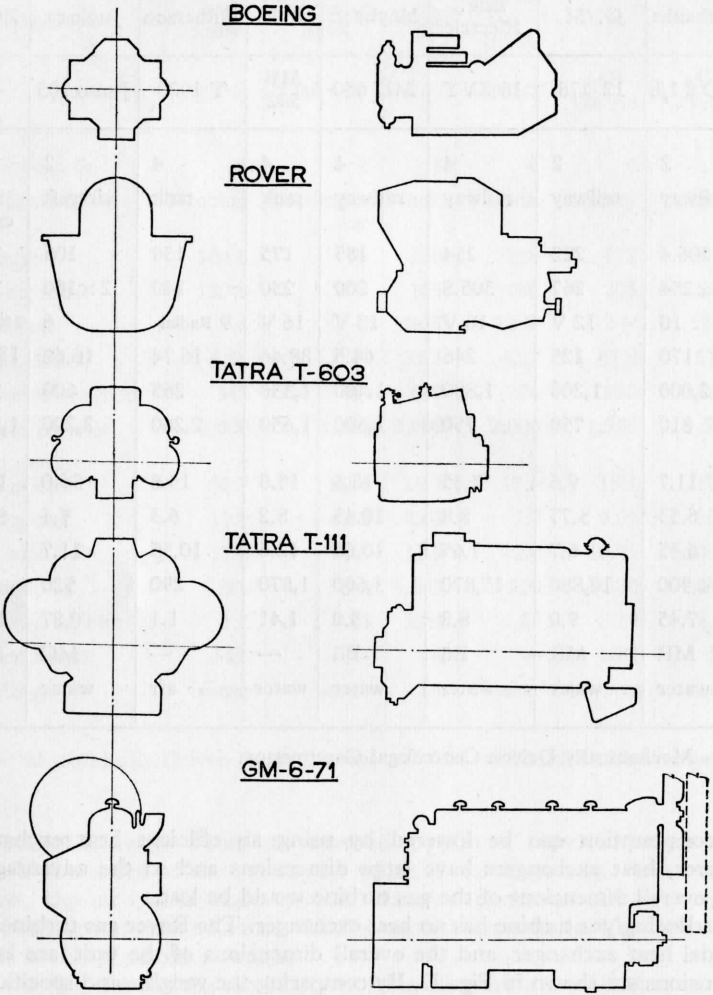


FIG. 27. Comparison of engine size with combustion turbines listed in table 5.