SECTION 2

INTRODUCTION

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2 INTRODUCTION

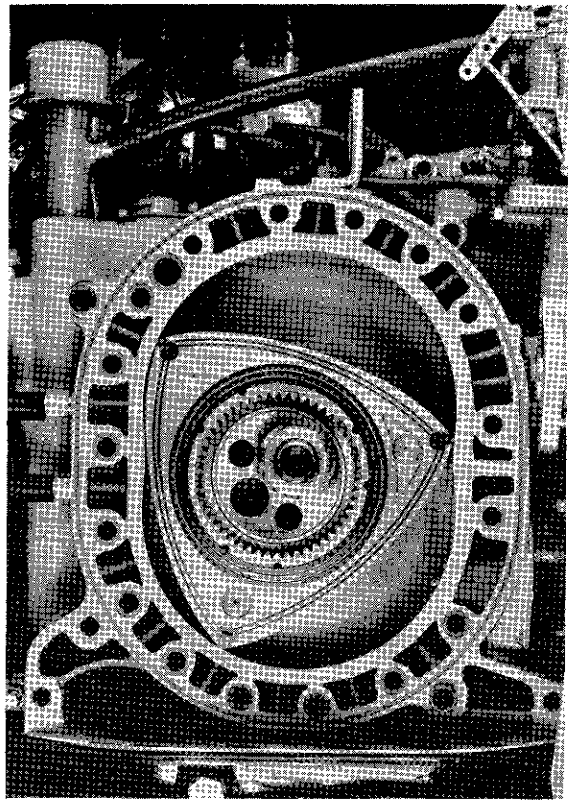
Many types of hovercraft, like aircraft, require a relatively high ratio of installed power/all up weight. To provide this power from conventional engines involves either a weight penalty from piston engines or a penalty, at least in initial cost, from the use of gas turbine engines. The emergence of the Wankel rotary combustion engine and its recent application in motor cars offers an alternative power plant with some of the attractions of both gas turbines and piston engines. Wankel engines are relatively light in weight and small in volume, intermediate between piston engines and gas turbines, and their design allows low cost manufacture and maintenance on account of their basic simplicity, even compared to conventional piston engines. The present study was required to report on the present position with Wankel engines and to suggest arrangements for substituting them as power plant in CC-7 and HM2 hovercraft.

2.1 OPERATION OF THE WANKEL ROTARY COMBUSTION ENGINE

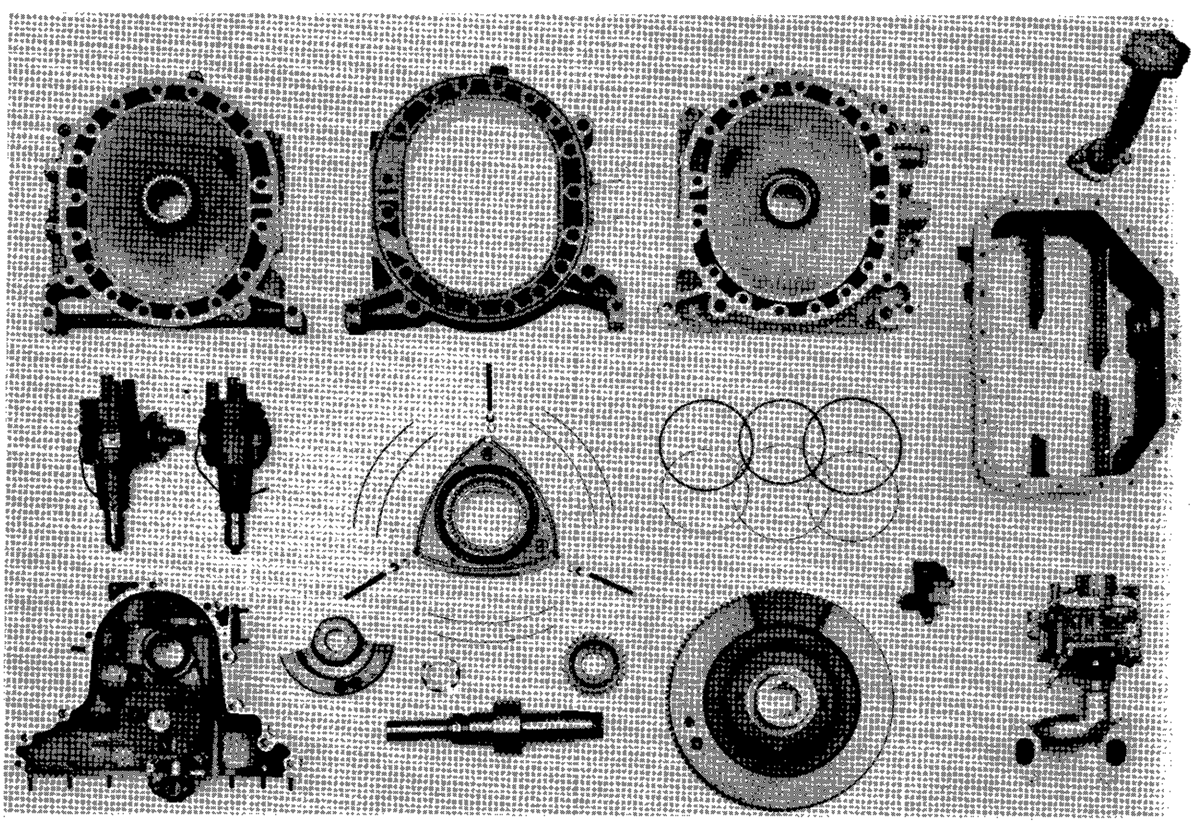
Many attempts have been and are being made to apply the Otto cycle of the conventional reciprocating engine in a purely rotary machine. Numerous engines have been designed and some have been demonstrated, but the only commercially successful design so far is that evolved by Dr Felix Wankel.

The first Wankel rotary combustion engine in the general form as it is now known, consisted of an inner member in the form of an equilateral triangle but with slightly convex sides, in a housing having two hollow lobes. They each rotated in the same direction but about different axes and were geared to revolve at different speeds, such that the three apices of the inner member were always in contact with the inner surface of the outer member. As a result, each of the three chambers, formed between the inner member and the housing, progressively increased and decreased in volume as the members revolved. By adding induction and exhaust ports, sparking plug and sealing arrangements between the two members, a viable engine was evolved which ran successfully early in 1957.

For practical reasons the design was inverted so that the inner member rotated within a stationary housing and thus became the rotor, while its axis itself moved in a circle about the axis of the housing and at three times the speed of rotation of the rotor. In practice, the rotor runs on an eccentric portion of the main shaft of the engine (also known as the eccentric shaft or output shaft), which runs in bearings on the centre line of the housing. Alongside the eccentric is a gear or pinion, which is fixed to the end cover and meshes with teeth of a ring gear attached to, or part of, the rotor, centred on the rotor axis, such that for every revolution of the rotor the shaft makes three revolutions in the same direction. This is the basic planetary rotation configuration of the engine that has been licensed, developed and produced in quantity and is the subject of this study.

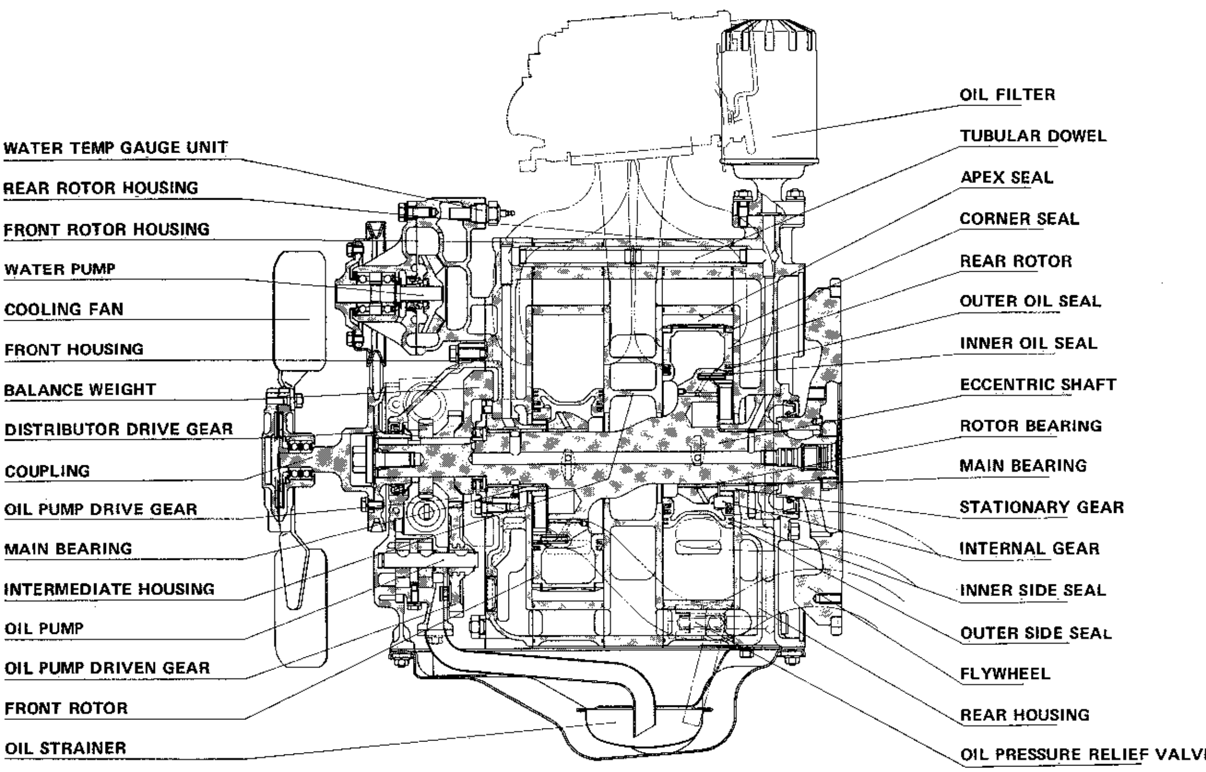


(a) 10 A engine (used in Mazda R.100 car)

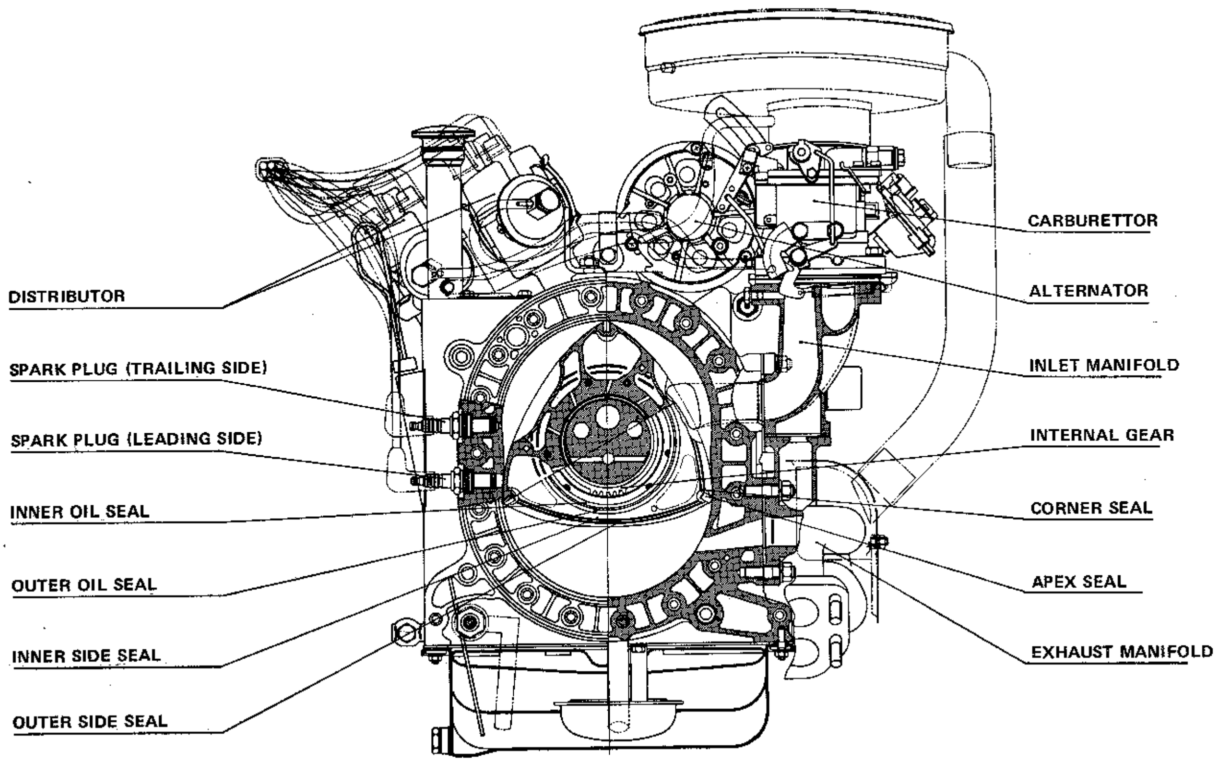


(b) 110 S engine (used in Mazda 110 Cosmo car)

Fig.2.1 Main components of typical Wankel engine (Toyo Kogyo)



(a)



(b)

Fig.2.2 Typical nomenclature of Wankel engines

In the Wankel engine the eccentric shaft essentially performs all the functions of a crankshaft. It rotates at three times rotor speed, but since the engine contains three chambers each passing successively through the four stroke cycle, it is usual, when describing the characteristics of a Wankel engine, to refer to the speed of the eccentric shaft rather than of the rotor, and to the displacement per revolution of the eccentric shaft.

Figure 2.1 is a photograph of the main components of typical engines (Toyo Kogyo) and Figure 2.2 shows the Toyo Kogyo 10A engine in section with typical nomenclature.

The four stroke (Otto) cycle of the conventional reciprocating piston engine comprises the following four strokes:-

1. Suction – increasing volume.
2. Compression – decreasing volume.
   (Ignition)
3. Combustion and expansion – increasing volume.
4. Exhaust – decreasing volume.

Figure 2.3 shows how the Wankel engine relies upon this cycle in each of the three chambers formed between the rotor and the housing as the rotor rotates, each stroke occupying approximately 90° of rotor rotation. (For clarity the figure shows the sequence of events in a single cycle chamber only.) Thus the Wankel is a true four cycle engine.

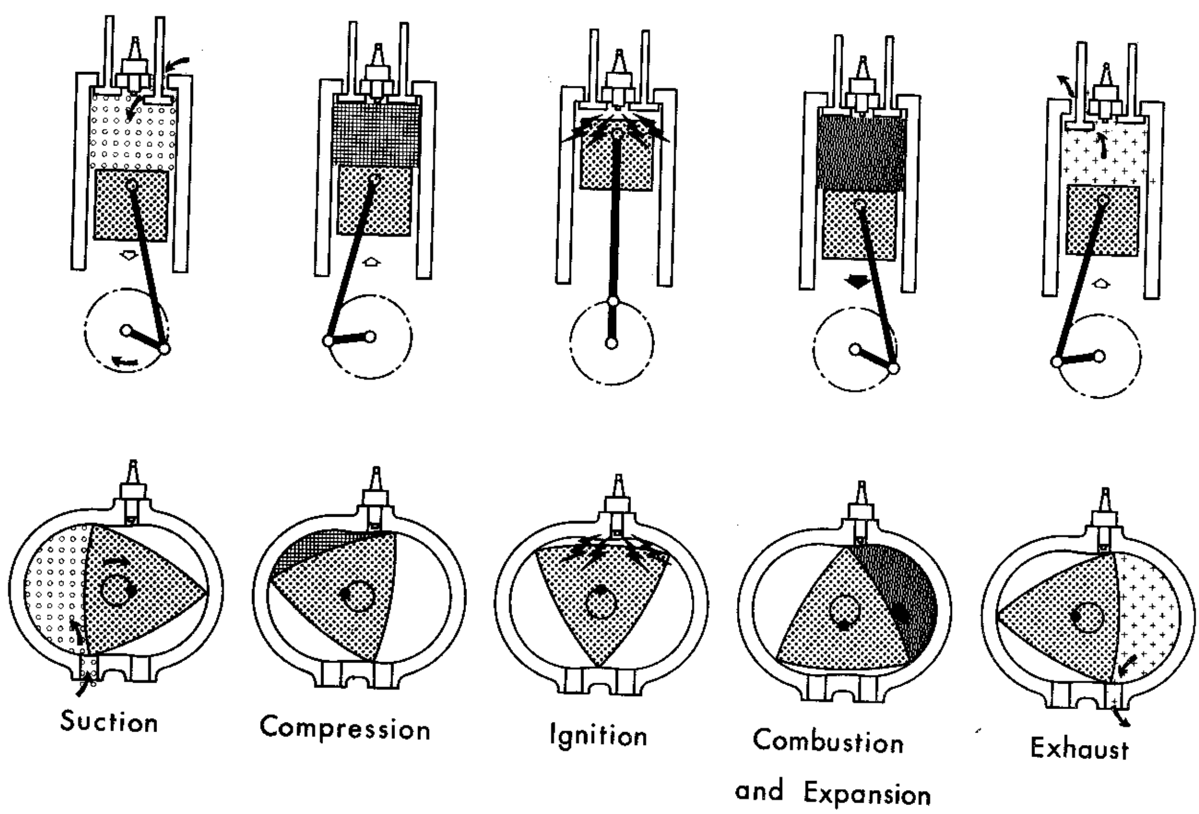


Fig.2.3 The corresponding phases of the thermodynamic cycle of a conventional four stroke piston engine and the Wankel engine. The power stroke is indicated by a solid black arrow

The force resulting from the expansion stroke passes through the axis of the rotor and so would not of itself cause the rotor to turn. However, it also passes through the centre of the eccentric part of the main shaft and the resulting moment causes the shaft to rotate and, since the rotor meshes with the stationary pinion it must also rotate. The function of the shaft thus corresponds with that of the crankshaft in a reciprocating piston engine.

The design of the engine is perhaps more complex than the above very simplified description suggests. The exact geometric form of the loci of the apices of the rotor is epitrochoid, the generation of which is explained in Appendix II. Effective sealing arrangements between the rotor and its housing are indispensible, on account of differential thermal expansion of the rotor and housing. The development of suitable sealing systems in fact preceded the invention of the Wankel engine. These sealing systems or grids consist of apex seals, to prevent the escape of gas from one chamber to another past the apices of the rotor, suitably linked to side seals to prevent leakage between the side faces of the rotor and the end covers. Effective sealing, as is the case with piston rings, depends on adequate lubrication. Apex seal lubrication is a total loss system; initially oil was added to the fuel but it is more usual now for oil to be metered in to the induction pipe by a separate pump. Lubrication of the bearings, gears, etc. of engines having oil cooled rotors (see below) is by the oil which circulates through the rotor. In engines having charge cooled rotors, the oil mist carried by the charge lubricates these parts. The oil system of NSU/Wankel engines merely needs topping up from time to time; oil changes are not needed as combustion products cannot come into contact with the oil as in reciprocating piston engines. So far, rotor cooling has proved to be essential: it may be achieved at a sacrifice of performance by circulating the incoming charge through it on its way to the induction stroke, or by oil circulation within the rotor. Charge cooling of the rotor implies an appreciable rise in charge temperature before it enters the chamber, with consequent lowering of the volumetric efficiency. It is therefore only used on engines which have a low bmep.

Inlet ports may be peripheral, entering through the rotor housing, or side, through the end covers. Peripheral inlet ports favour high speeds and top end performance while side inlet ports confer higher torques over the lower speed range at some sacrifice of high speed power output. Exhaust ports are usually peripheral.

In the Wankel engine the charge moves round inside the housing, consequently the individual parts of the thermodynamic cycle – induction, compression, expansion and exhaust – occur always in the same section of the housing, parts of which are thus subjected only to successive hot cycles, without any surface cooling effects provided by fresh charges, as occurs in the reciprocating piston engine. Combustion also tends to be slower in the Wankel. Due to the slower combustion, the temperature of the exhaust gases are somewhat higher than in reciprocating piston engines. This is a feature of the engine and does not imply lower thermal efficiency. It is a peculiarity of the Wankel engine that in spite of the higher exhaust temperature, the peak combustion temperature is appreciably lower.

So far, reference has only been made to an engine consisting of a single rotor in a single housing. However, additional rotors and housings can be added and most of the current automotive engines are twin rotor machines, while three and four rotor engines also exist.

The rotary combustion engine is not confined to the two lobed housing, triangular rotor configuration: in theory the housing may have any number of lobes, provided it is capable of accommodating a sensible thermodynamic cycle. Additionally, either the rotor or the housing may be the working component.

2.2 OTHER TYPES OF ENGINE CURRENTLY AVAILABLE

Taking the lightweight or automotive diesel as the heaviest acceptable engine, the present range of engines available commercially may be summarised, (in ascending weight/power ratio), as:-

(a) Aircraft gas turbines.
(b) Industrial and automotive gas turbines.
(c) Aircraft piston engines.
(d) Automotive type petrol engines.
(e) Lightweight and automotive diesels.

Representative examples of the various types of engine are shown in Figure 2.4 and a brief list of engine particulars is given in Appendix III.

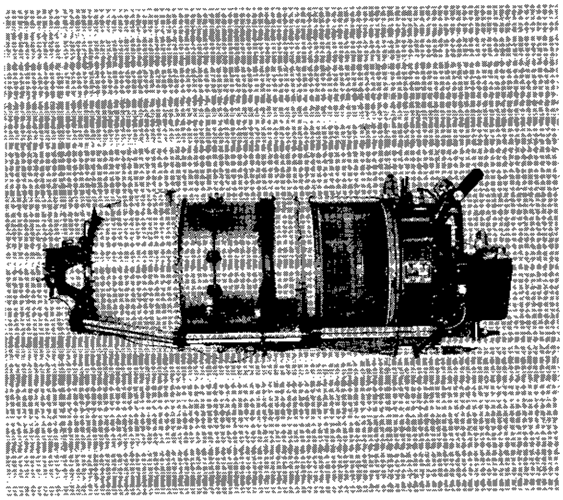
It will be seen that an upper limit of 700 hp has been assumed in this report. This is arrived at for several reasons. It would appear that the maximum power available from Wankel engines in the foreseeable future is from the double bank Daimler-Benz M 950 as proposed by Hoverprojects, or the Rolls-Royce project, both giving of the order of 700 hp. This power is roughly at the upper limit of small aero, large automotive and small industrial gas turbine engines, and is also suitable for a range of small to medium size hovercraft.

2.2.1 Aircraft Gas Turbines (and marinised versions)

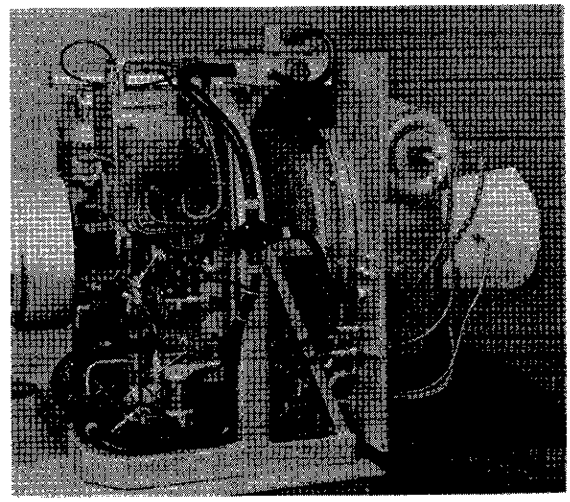
These have many mechanical advantages for hovercraft, being light, easily maintained, vibration free and relatively small, but they are very expensive and tend to have a higher fuel consumption, especially under part load conditions, than a Wankel engine.

2.2.2 Industrial and Automotive Gas Turbines

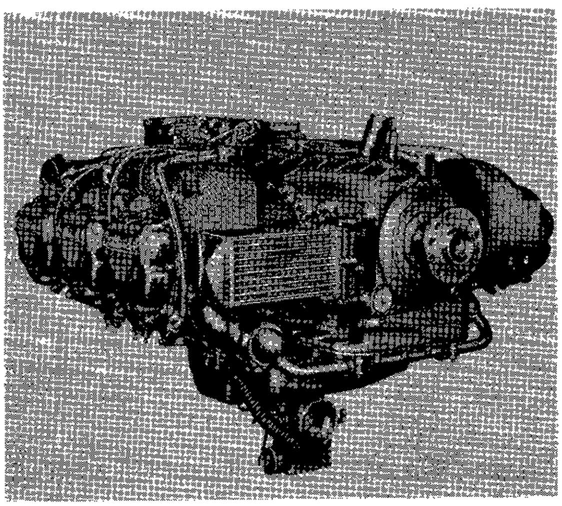
Many of the smaller industrial or marine gas turbines are based on aircraft units and generally have the same advantages, although some are to some extent heavier, particularly packaged units mounted on sub-frames. In price per horse power many are cheaper than aero gas turbines by a factor of 4 or more, and if the several automotive units being developed become available, could present a useful range of prime movers.



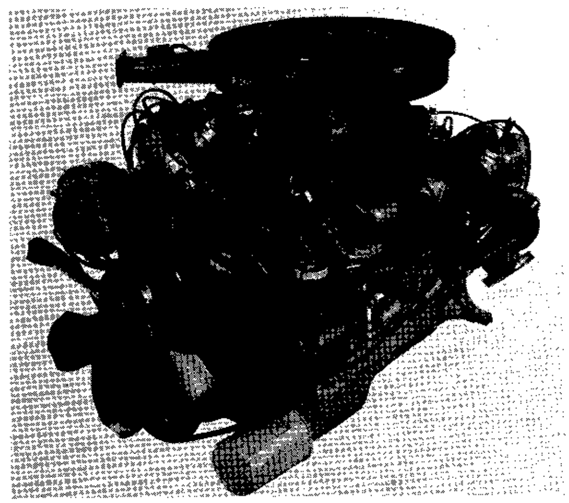
United Aircraft of Canada ST 6 A.



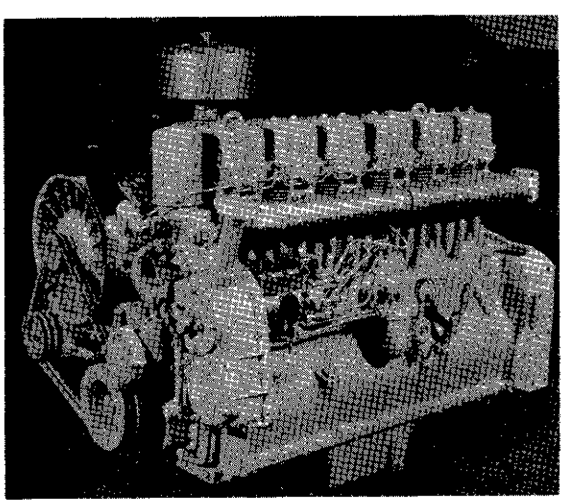
STAD IS-250 B.



Rolls-Royce Continental IO-470 C.



CHRYSLER 440 D.



DORMAN 6 DAT E.

Fig.2.4 Lightweight engines suitable for Hovercraft

A. Aero gas turbines.
B. Industrial and automotive gas turbines.
C. Aero piston engines.
D. Automotive petrol engines.
E. Lightweight diesel engines.

However, one major disadvantage of the gas turbine, both aero and industrial, is the large volume of air required. For example, the STAD IS/250 (marketed in the U.K. by Auto-Diesel Ltd.), at 250 hp output requires 76 cu. ft. per second. Ideally, inlet velocities will be of the order of 10/15 ft. per second, so it will be seen that intake areas and filters add considerably to the weight and require to be large, creating space and craft profile problems which are avoided with rotary or piston engines.

2.2.3 Aircraft Piston Engines

This type provides a group of engines suitable for hovercraft and being (generally) air-cooled give simple installations at a reasonable price. They are, however, quite noisy, generally use petrol and offer cooling problems due to slow air speeds encountered on hovercraft.

2.2.4 Automotive Type Petrol Engines

For some air cushion vehicles the low cost of this class of unit and, as shown in Figure 2.5, their power/weight ratio, can be attractive at the top end of their power range. However, where minimum engine weight is a requirement the power/weight ratio tends to suffer as a result of the appreciable derating normally considered necessary for continuous operation, (see Table 5.1). In the case of craft for passenger carrying duties, Board of Trade certification precludes engines using petrol.

2.2.5 Automotive and Lightweight Diesel Engines

Where a measure of weight disadvantage can be accepted these engines are exceedingly useful, as in craft like the HM2. Their main advantage is in their low specific fuel consumption and safe operation in that they use fuels with high flash points. Their cheapness, compared to the equivalent gas turbine, low fuel running expenses and insurance, give very economical operating costs. Adversely, they are noisy, require more maintenance and produce more vibration than other engines.

2.3 THE WANKEL COMPARED WITH OTHER ENGINES

The ideal engine for hovercraft would combine light weight, small bulk, low first cost, operating economy, low vibration levels, safety, reliability and ease of maintenance. Figure 2.5 shows how the Wankel engine compares with other types over the first four of these parameters while the latter three are dealt with in Sections 5 and 6. The Wankel engine, while not free like the gas turbine of cyclic torque fluctuations, is considerably better than the reciprocating piston engine (see 7.1).

A broad conclusion from Figure 2.5 is that although the Wankel engine is not markedly better than existing engines in any one characteristic, nevertheless it is more consistently at the favourable end of the range and, taking an overall view, shows to advantage. There would seem to be evidence that the degree of derating from maximum to continuous maximum output is

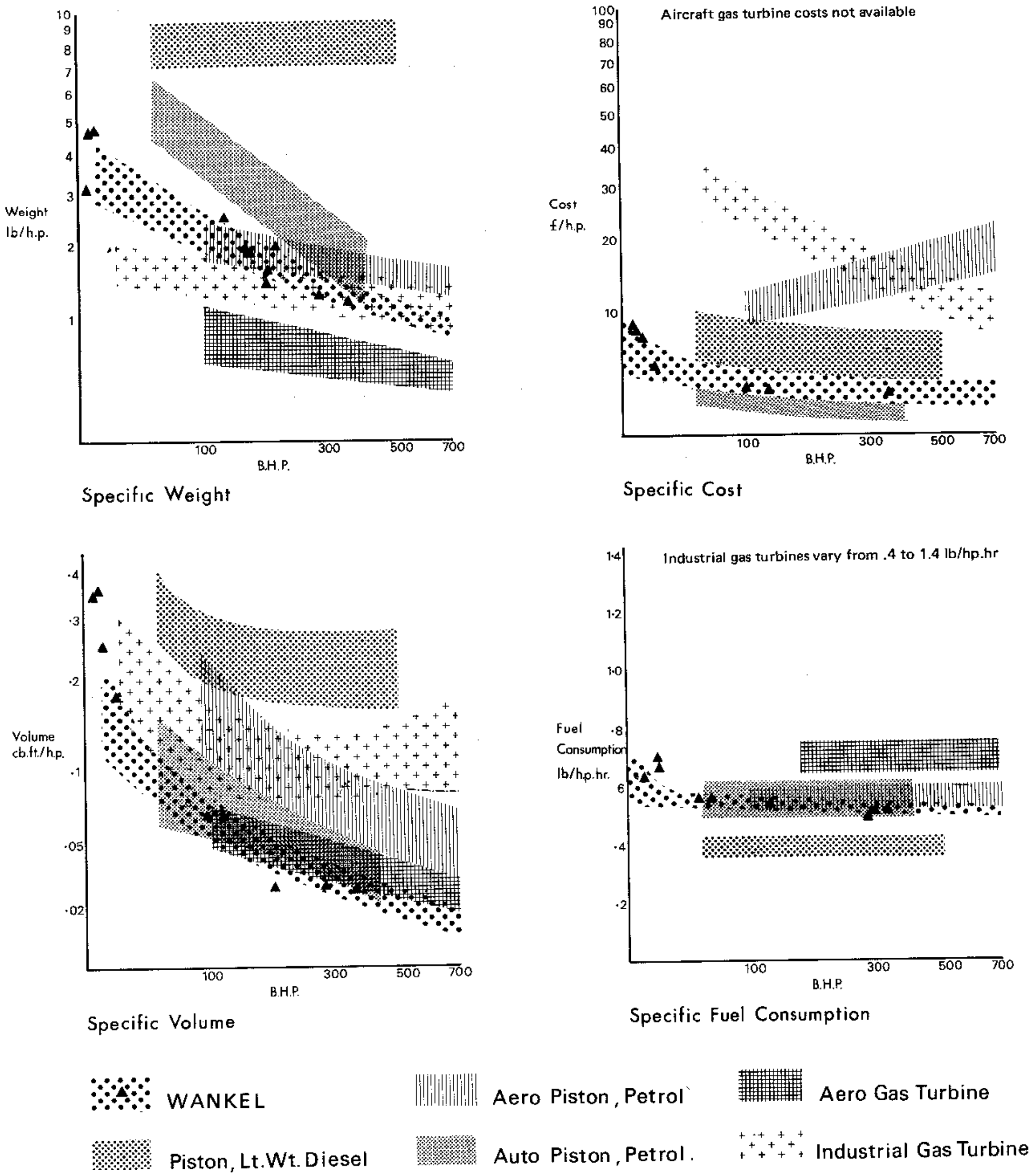


Fig.2.5 Comparisons between the Wankel and other types of engine available for hovercraft
Complete information not available for all curves

less in the case of the Wankel engine than for automotive type piston engines. The Wankel has fewer parts than its piston equivalent, (Figures 2.6 and 2.7), would appear to be less likely to suffer major internal damage and is quicker to strip and reassemble for overhaul, though at its present state of development, top maintenance may take slightly longer.

It has to be borne in mind that the Wankel engine, at the present stage of development, is being compared with other types which have a much longer history of development behind them. It would be fair to assume that with normal further development, for example, replacing carburettors by fuel injection, to reduce bulk and possibly fuel consumption, and a wider use of light weight materials, the Wankel engine will show to even greater advantage in the reasonably near future.

One manufacturer, M.A.N. AG, has stated that their engines when fully developed should be competitive with gas turbines up to 600 hp. This sort of confidence in the Wankel engine potential should give grounds for serious examination of the rotary engine when proposing or designing a new small craft even whilst engines are not available in commercial quantities.

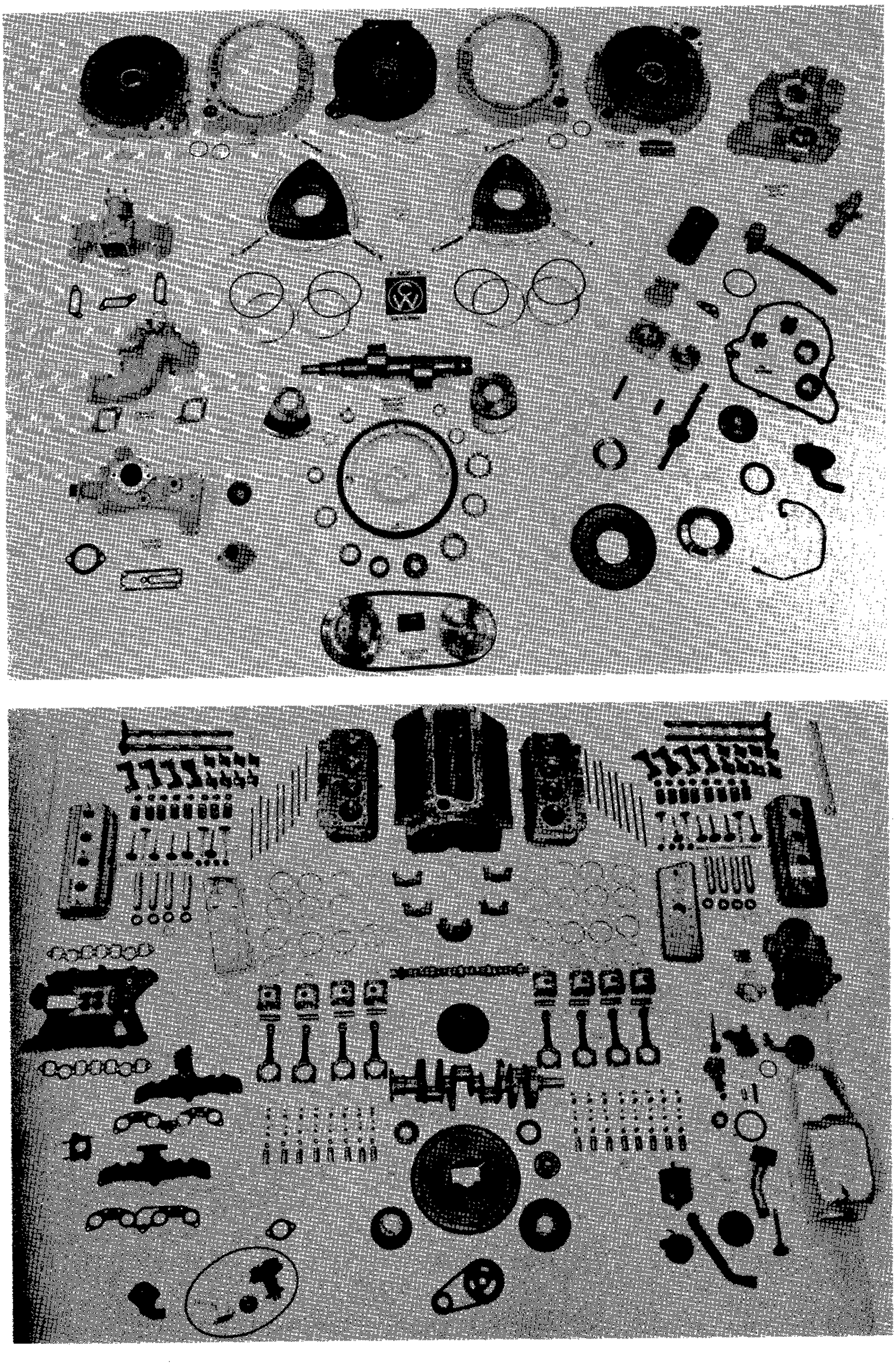


Fig.2.6 Comparison between 2-rotor Wankel and V-8 piston engine

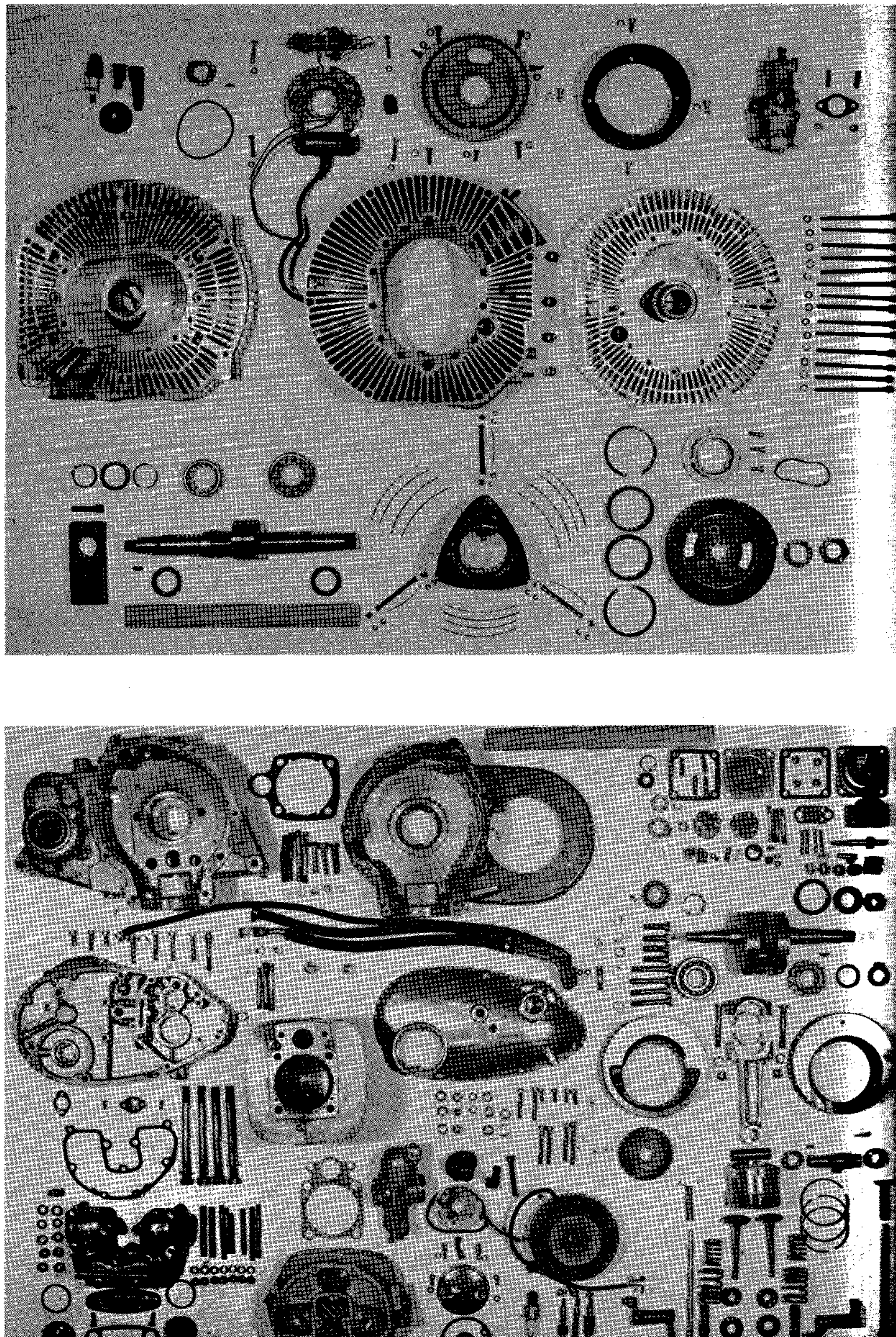


Fig.2.7 Comparison between single rotor Wankel and single cylinder piston engine