SECTION 3

A SURVEY OF THE PRODUCTION AND DEVELOPMENT POSITION

3 INTRODUCTION

No British companies are producing Wankel engines. The only firms currently engaged on engine development in this country are Rolls-Royce and the B.S.A. Group Research Centre. Work is also proceeding at B.S.A. on silicon nitride apex seals and Plessey are developing an ultrasonic fuel atomisation system. Work similar to Plessey's was in hand at Simms Group Research and Development Ltd. but is now stopped.

(See Appendix IV for details of engines in full or experimental production.)

3.1 FIRMS MANUFACTURING WANKEL ENGINES IN PRODUCTION QUANTITIES

3.1.1 NSU

NSU are, with Dr Wankel, the licensors for the Wankel engine. They developed the single rotor, water cooled KKM 502 engine which went into limited production for the Spider car. A twin rotor engine was subsequently developed which became the KKM 612. This is the engine currently in production for the Ro80 cars, Figures 3.1 and 3.2. It is a water cooled unit developing 113.5 bhp net, and follows normal automotive practice in incorporating radiator fan drive, power steering pump and generator drive. Power take off is via an automotive torque converter, whose housing forms part of the gearbox.

The normal production KKM 612 car engine is available in small numbers from NSU subject to top management approval. Engines could also be obtained as 'spares' from local agents, but at a much higher price.

A three rotor engine is being developed for an output of about 170 hp, and work has been carried out on an engine for the Comobil European car, details of which are not available.

A fully marinised version of the KKM 612 engine is the basis of the Ro135 marine Z drive units, Figure 3.3, which also comprise a heat exchanger and an inboard-outboard Z drive from Zahnradfabrik Friedrickshafen. The unit is not available in the U.K. however, both NSU and ZF having decided to stop work on their respective parts of the unit because it diverts resources away from their main production activities.

It is interesting to note that Dr Wankel's own Ro135 engine has been developed to deliver 153 hp: further development is in progress at his research establishment at Lindau with a target output of 200 to 220 bhp.

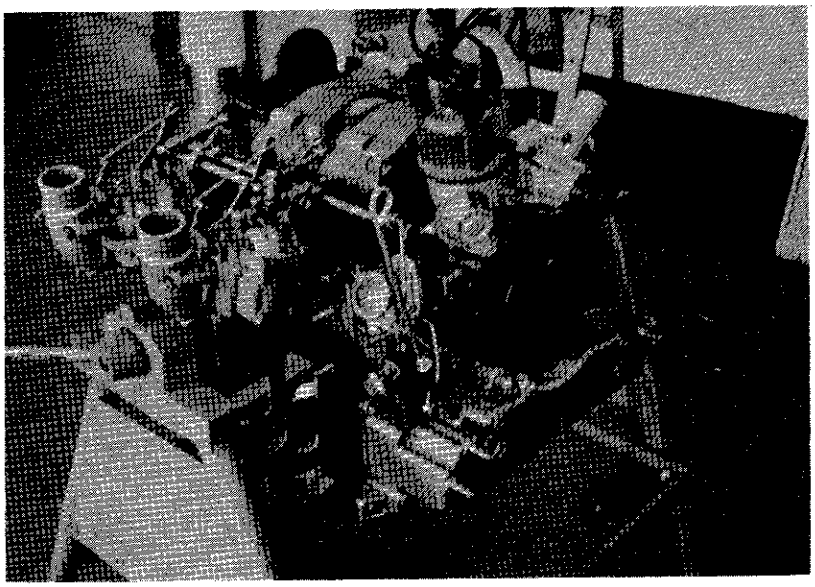
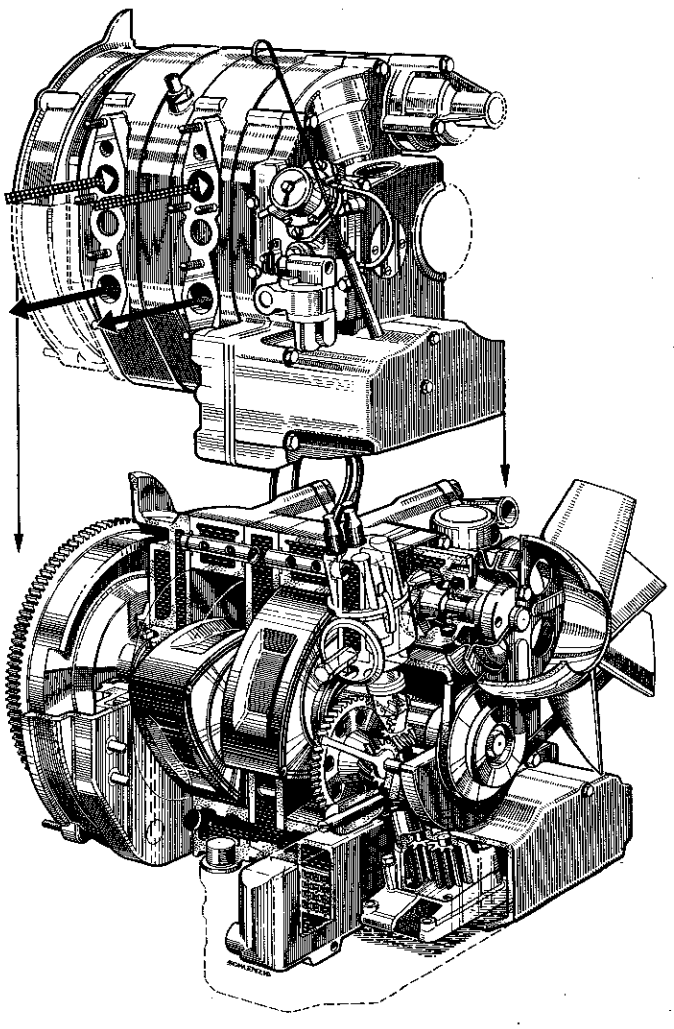


Fig.3.1 NSU type KKM 612 engine as used in Ro80 motor car



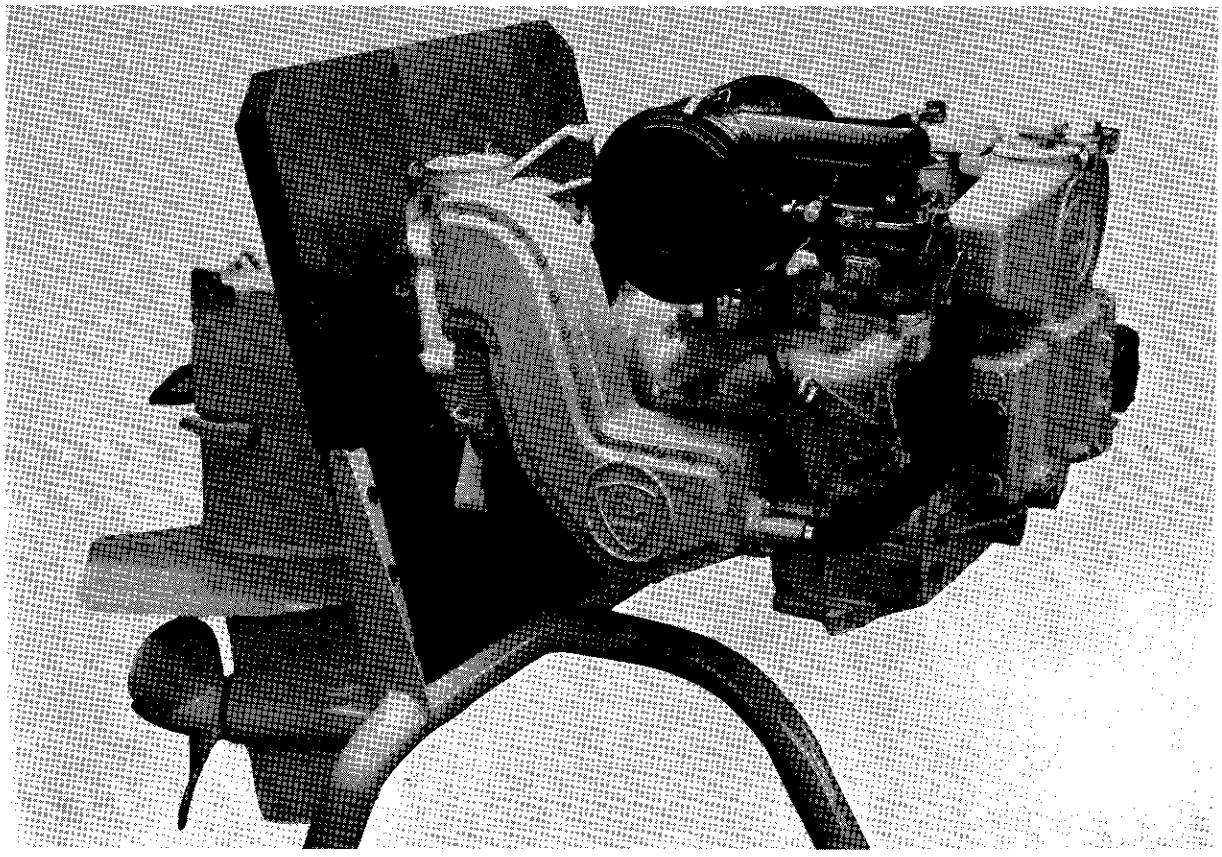


Fig.3.3 Photograph of NSU Ro135 marine Z-drive unit

3.1.2 Toyo Kogyo Co. Ltd.

The 10A, (Fig.2.2), is the standard power unit for the Mazda R 100 car. Although there are differences in detail design and materials, this engine is essentially similar to the NSU KKM 612 and develops 110 hp SAE at 7,000 rev./min. from twin rotors. The variations between the two engines generally would not affect an installation, and they could be considered as interchangeable units depending on the part of the world for which a particular craft was destined. The mileage between overhauls of the 10A is claimed as being some 25% better than the NSU KKM 612 and it is purported to be more reliable.

Toyo Kogyo made a similar engine, but lighter, for the earlier Cosmo 110S car, which is still available, and a limited number of increased capacity, wider rotor engines developing 126 bhp at 6,000 rev./min., are being made for the R 130 car, which, however, is only marketed in Japan. Another engine, the RX 2, powers a new car which recently came on the market in Japan and is expected to be available in this country late in 1971. This engine is similar to the 10A but has 10 mm wider rotors and is rated at 130 hp SAE. Side inlet ports are used on these engines whereas NSU use peripheral ports. Mention has been made of a small prototype town car built by this company, with electric drive and battery charging by a rotary engine (Fichtel & Sachs) running at constant speed*.

* Automotive Design Engineering, December, 1970

The production rate of Wankel engines at Toyo Kogyo is the highest of any Wankel engine licensee and is inspired by the declared policy of changing over completely to Wankel engines for all cars made by this company. Research and development on conventional engines has been discontinued.

It is unlikely that the Toyo Kogyo Co. Ltd. will supply Wankel engines for installation in hovercraft without prior written consent from the NSU/Wankel organisation, and even with this consent it would seem advisable to establish direct contact with the management. It has been suggested that it may even be possible to encourage the company to make certain four rotor versions available for hovercraft applications.

3.1.3 Fichtel & Sachs AG

This company manufactures the following small, single rotor, air cooled engines with charge cooled rotors (Fig.2.7):-

KM 48, delivering 10 hp
KM 914, delivering 20 hp

This is the only company able to offer rotary engines not requiring extensive modification, the only restriction on sale being a maximum of 20 hp (at 5,000 rev./min.) imposed by the licensing agreements.

Quite a few KM 37 (now discontinued), and KM 48 engines have been used in Australia and New Zealand for various industrial and agricultural purposes as well as auxiliary power units for yachts. Indeed, the demand for engines in Australia, where import duties may be as high as 85%, is stimulating the desire to build various Fichtel & Sachs units locally on the basis of a sub-licence agreement. It is not yet known when this agreement will come into force.

A derivative of the KM 48 (no cooling fan), is used as an auxiliary power unit for the K.S.B. power assisted glider. However, the thrust developed would be of no use to any but the smallest hovercraft.

By far the largest number of KM 914 engines are used for snowmobiles in Canada and the U.S.A. It is now being fitted as standard by the Peterborough company, Hover-air Ltd., on the 'Hoverhawk', replacing the Velocette 'Viceroy' twin cylinder piston engine, and it also powers a small, single seat aeroplane somewhere in the north of England. It is a very popular engine with those companies and organisations carrying out development work on the Wankel engine, e.g. Plessey, C.A.V., Simms, B.S.A. Group Research Centre* and M.V.E.E. (Christchurch

Two 30 hp engines are under consideration: one, on the lines of the KM 914 is still under study and unlikely to enter production in the near future. According to the terms of the licence, this would only be available for snowmobiles. The other is an air cooled, twin

rotor engine on which development has been stopped indefinitely. A water cooled version of the KM 914 weighing 73 lb bare, is being developed.

3.1.4 Yanmar Diesel Co. Ltd.

Yanmar Diesel are producing two outboard motor units, the R 220 and R 450, powered by water cooled, single rotor engines developing 20 and 45 hp respectively, and running on petrol. Prices are comparable with piston engined outboard units; the engines themselves are slightly heavier than orthodox units.

It is possible that bare engines could be available, subject to the agreement of the licensors.

The R 220 was first marketed in 1969 and the R 450 in 1970, so no information is available regarding operation or life.

Engines in production range from 3 to 50 hp. Importance has been placed in development on superior engine performance and reliability compatible with low cost production. Their use on rotary tillers, snow clearers and fire pumps, as well as outboard motors, is being tested.

3.1.5 Johannes Graupner

The 4.9 cc engine marketed by Graupner is manufactured in Japan by O.S. and is intended for model aeroplanes but could find application in dynamic models.

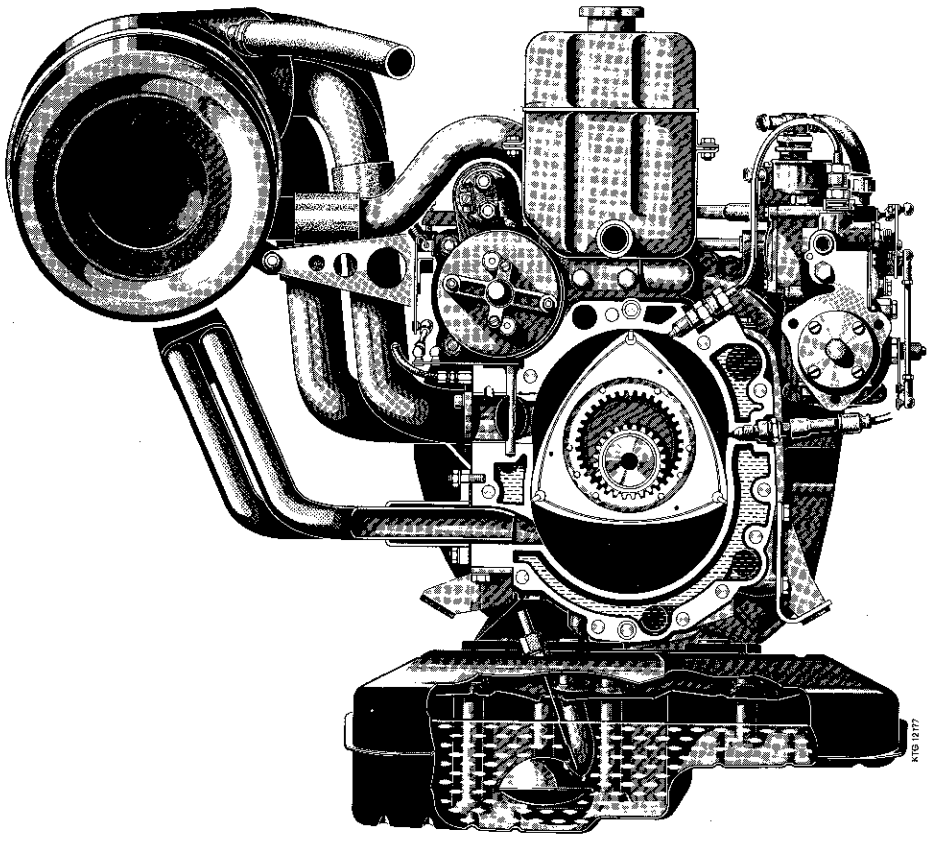
3.2 LICENSEES WITH ENGINES IN AN ADVANCED STAGE OF DEVELOPMENT

3.2.1 Daimler-Benz (Mercedes)

At the moment Daimler-Benz are working on two, three and four rotor versions of the type designated M 950. Examples of the three and four rotor engines were used in the 1969 and 1970 C 111 research cars respectively. These are liquid cooled, automotive units delivering 280 and 350 bhp with fuel injection.

Efforts are being concentrated on the four rotor version and a batch is being assembled at Stuttgart for evaluation.

Daimler-Benz are not in production with any Wankel engines, and evidence within the workshops suggests that this company is engaged on a major research and development programme; however, one could say that preproduction runs are going through the workshops. During the discussion held at Stuttgart on the 2nd June, 1970 – attended by Mr R.A.Shaw of Hoverprojects Ltd. and Regierungs-direktor Mack from Bonn – it became clear that Daimler-Benz realised that they could not withold their Wankel engines from certain research projects and



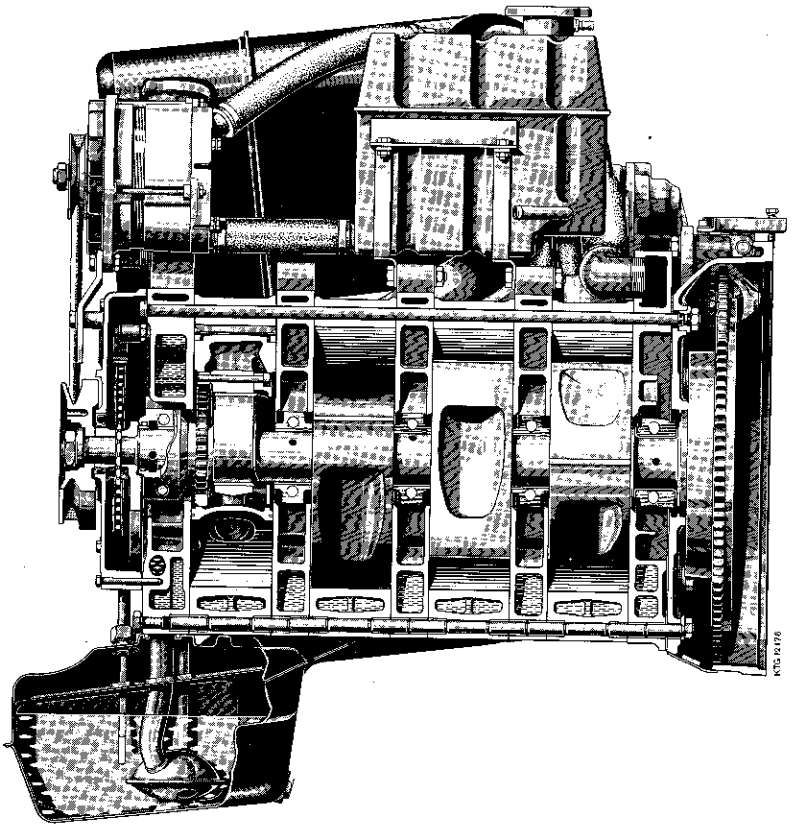


Fig.3.4 Sectional drawing of Daimler-Benz 4-rotor M 950 engine as used in the C 111

from various organisations for very much longer. For instance, some engines will be made available to the MTU consortium for long term aero engine developments.

The suggestion arose in discussion that the German Ministry of Defence and the British Department of Trade and Industry might co-operate to back a joint project on the application of the Daimler-Benz engines to hovercraft. It would be possible, for example, to run a test rig with two coupled Daimler-Benz Wankel engines in the research laboratory at Stuttgart University which is convenient for the factory, and this could be sponsored by a modest research contract (see also 9.4).

3.2.2 Curtiss-Wright Corporation

This company has been developing their own version of the Wankel engine since 1958*. Most of their extensive work has been concentrated on a rotor size giving a displacement of 60 cu. in., and resulted in achieving a performance in terms of specific fuel consumption, oil consumption, idling consumption, and general performance on the road, for an automotive twin rotor version weighing 237 lb with alternator and normal auxiliaries, which was comparable to that of a V8 piston engine weighing 610 lb. Most of this work was on twin rotor engines, but a four rotor version has also been tested.

The same basic unit was used for the development of a fuel system comprising high pressure injection into the combustion chamber, with spark ignition, to enable a range of less volatile fuels than petrol to be used, (diesel No.2, JP4 and JP5). An attempt to extend the multi-fuel capability of this unit was made recently, (since 1968), with the assistance of Rolls-Royce, under a contract from the then F.V.R.D.E.

In addition to the automotive applications, marine and aircraft prototypes of the twin rotor, 60 cu. in. displacement per rotor, liquid cooled unit were built and tested. An engine was also run as the prime mover of an electrical generating set, rated at 60 kw.

Curtiss-Wright's work has included limited development of other sizes of rotor, (including 4.3 and 1920 cu. in. displacement), and more extensive development of a twin rotor, air cooled, aero engine of 90 cu. in. displacement per rotor, running on JP5 fuel with high pressure injection. Details of this engine, type RC2-90-Y2, which is rated at 310 hp at 6,000 rev./min., are given in Appendix IV. This unit retained the same rotor proportions as the 60 cu. in. engine but the axial width was increased.

Curtiss-Wright state that the engines referred to in Appendix IV are prototypes of an experimental nature and are not in production status. Four prototype engines which have been tested at M.V.E.E. and Rolls-Royce, Crewe, are no longer available.

* See reference to several papers by Jones, C., in the bibliography.

Curtiss-Wright have also turned their attention to exhaust emissions. Work carried out in conjunction with the University of Michigan on an exhaust gas reactor used on an RC-2-60 automotive prototype looked promising*. This subject is dealt with in greater detail under Appendix IX.

3.3 OTHER WANKEL LICENSEES KNOWN TO BE DEVELOPING ENGINES

3.3.1 Rolls-Royce Ltd.

The Crewe division of Rolls-Royce has for some years been working on the application of the compression-ignition cycle to the Wankel engine for military applications, sponsored by M.V.E.E. They have evolved a configuration which relies upon the basic Wankel planetary rotation principle, but incorporates two stage compression and expansion. Each stage consists of the familiar triangular rotor rotating in an epitrochoidal housing. The shafts from each stage are geared together so that both will rotate at the same speed and in the same direction. Unlike the high pressure rotor, the flanks of the low pressure rotor have no depression. Air entering the low pressure stage is compressed between the two rotors until the inlet transfer port closes. After fuel is injected around top dead centre in the high pressure unit, the expanding gas is returned via the exhaust transfer port to the low pressure stage, from which, after further expansion, it is exhausted†.

A prototype two stage engine as described had run for 800 hours at the time this report was written with encouraging results and a larger, double bank engine, the 2-R6, was being designed and manufactured. This engine has a displacement of 3,250 cc per bank, and is expected to develop 350 bhp at 4,500 rev./min. for a weight of 929 lb. The engine has been designed so that further banks can be added to meet power requirements of up to 1,000 bhp.

According to Rolls-Royce, it appears that the 2-R6 engine will be more compact than diesel engines or automotive gas turbines of similar performance. Most of its components have been individually tested, including the high pressure unit, and the first complete engine is expected to be ready to start tests in February, 1971. It is, of course, impossible to forecast the time required to develop the 2-R6 engine up to the point where it is ready to go into production.

Before this type of engine can be released for commercial application it is likely to prove necessary to extend engine life beyond what is acceptable for military applications. It should eventually be a potentially interesting unit for hovercraft requiring engines in the 350 to 1,000 range.

* Cole, D.E., and Jones, C., Reduction of emissions from the Curtiss-Wright Rotating Combustion engine with an exhaust reactor.

† Feller, F., The 2-stage Rotary Engine – a New Concept in Diesel Power.

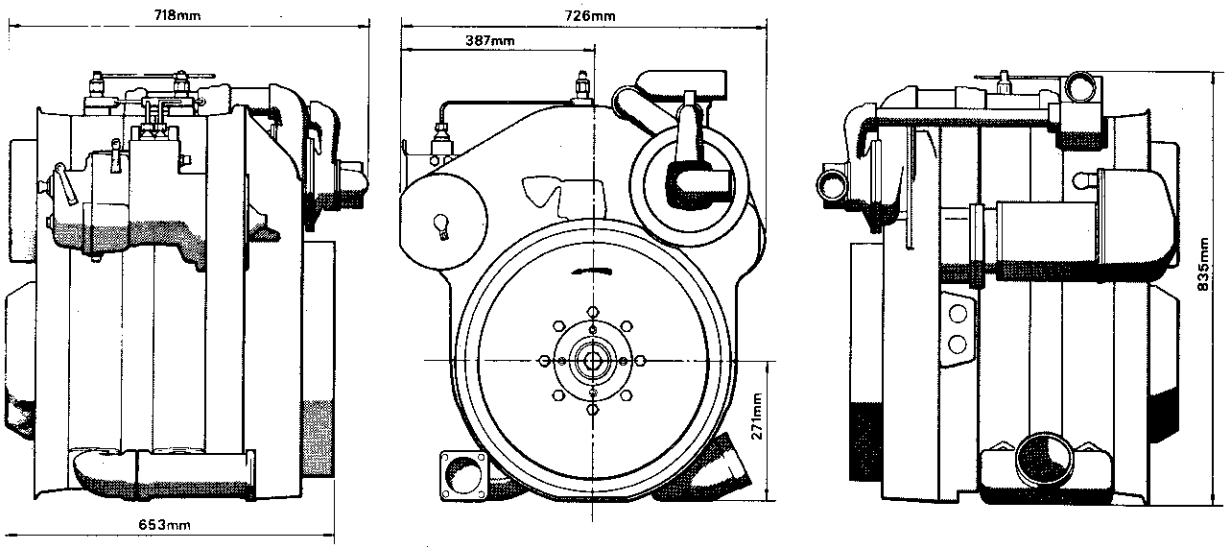


Fig.3.5 Arrangement drawing of Rolls-Royce 2-R6 engine

3.3.2 Klöckner-Humbolt-Deutz

Unwilling to supply information. The company states that their Wankel work has been suspended to enable them to concentrate on diesels.

3.3.3 Dr Ing. h.c. F.Porsche

Increasing work on exhaust emission and safety aspects of conventional engines leaves little, if any, capacity to develop the Wankel: unwilling to comment or reveal experience.

3.3.4 Outboard Marine Corporation

It is understood that a range of Wankel engines is being productionised. The Corporation's policy precludes revealing information.

3.3.5 M.A.N. AG

This company's development of a compression-ignition Wankel engine has not yet progressed sufficiently for them to think of offering it for sale.

3.3.6 F.Krupp GmbH

Although their licence is for diesel engines, Krupps have opted for fuel injection similar to that fitted on diesels, with spark ignition. The current project is a basic one litre swept volume, single rotor unit having an output of 100 hp and a specific weight of 1.76 lb/hp.

3.3.7 Alfa Romeo

Alfa Romeo are working on prototypes for possible automotive applications and have projects for water cooled, single and twin rotor units of 500 cc displacement per rotor,

developing 60 and 125 hp and weighing 150 and 198 lb respectively. Present work is mair concerned with higher power and different fuel feed systems.

3.3.8 F.Perkins Ltd.

Have stopped work and their licence seems to have lapsed.

3.3.9 Comotor SA

At the time of writing it was not known whether a single or twin rotor engine wou be used in the Comobil car.

3.3.10 Vereinigte Volkseigener Betriebe Automobilbau (E. Germany)

No information released.

3.3.11 General Motors Corporation, Detroit

Have recently signed a licence agreement and have presumably carried out some de ment work, but no information is available.

3.4 DEVELOPMENTS BY NON-LICENSEES

Although it is obvious that the major share of research and development work is c out by the licensors and licensees, it would be wrong to assume that they are alone in the Indeed, the following are, amongst others, examining various facets of the Wankel engine.

3.4.1 Major Car Manufacturers

Apart from General Motors, the Ford Motor Co. is exploring the matter through T Kogyo (Mazda), Japan. Chrysler are also understood to be interested. British Leyland ha so far indicated a positive interest.

3.4.2 B.S.A. Group Research Centre

Perhaps the most far reaching contributions under this heading are being made by B.S.A. Group Research Centre with the development of silicon nitride type apex seals, wh are known to possess superior wear characteristics, and are being tried by NSU and Daiml Benz. (See Appendix X.)

Although not licensees, B.S.A. Group Research Centre are developing an air coole rotor unit based on the Fichtel & Sachs KM 914 engine and with their co-operation, prim for motorcycles.

The power is expected to be approximately 50 hp and cooling is by free air flowi over radial fins compared to the KM 914 integral fan with axial finning. The prototype successfully during November 1970. By mounting a series of engines on to a common ge power plants of greater output would be available. An immediate proposal is a 100 hp u

having an opposed pair of double rotor engines suitable for light aircraft, hovercraft, etc., whilst developments could include a 200 hp cruciform unit.

3.4.3 Plessey Company

Work is in progress at the Plessey Company on the development of an ultrasonic fuel atomisation system for piston and rotary engines using spark ignition, with the object of improving their multi-fuel capability and of reducing exhaust emission. A Fichtel & Sachs KM 914 engine is being used. Various grades of kerosene, diesel and wide-cut fuels are being tried, in addition to petrol.

3.4.4 Prof. Huber's Research Establishment in Munich and West Berlin

Various contract work for the Wankel GmbH, Daimler-Benz and others.

3.4.5 Prof. Eberon von Eberhorst, Dean of the technical faculty of the University of Vienna. Performance and cooling peculiarities of air cooled Wankel engines as well as exhaust emission problems.

3.4.6 Dr David Cole, (son of Ed. Cole, President of G.M.C.), at Ann Arbor University of Michigan. Produced the first exhaust reactor for the Wankel engine, under contract arrangement with Curtiss-Wright. (See 3.2.2.)

3.4.7 Prof. E.Starkman, at the University of California, Berkeley, is working on exhaust emissions, especially those from leaded fuels. The Wankel engine is included in his investigations.

3.4.8 The Friedriche Goetze AG, Burscheid, Germany, has long been developing sealing component materials and their manufacturing techniques. They are the main suppliers in Germany.

3.4.9 The Robert Bosch GmbH, Stuttgart, continues its work on fuel injection and ignition systems in close association with Daimler-Benz.

3.4.10 Brico of Coventry are supplying sealing elements.

3.4.11 The Military College of Science at Shrivenham, has a long standing interest in stratified charge engines, including Wankel engines.

3.4.12 Prof. Lin and Dr Hopkirk have also investigated the stratified charge characteristics of the Wankel engine at King's College, London. Lack of time and finance seem to have brought this project to an end. Prof. Lin is now at Cummins in the U.S.A. and Dr Hopkirk at Vickers Ltd.

3.4.13 Nottingham University have run a Fichtel & Sachs engine on propane. Performance was comparable with petrol.

3.5 SUMMARY

The above survey may be briefly summarised as follows:-

3.5.1

For small hovercraft which can use engines burning petrol, the air cooled 10 and 20 h Fichtel & Sachs engines are available and are being used. B.S.A., although not licensees, are developing a twin rotor version of the larger unit to develop about 50 hp, which could also b coupled in pairs or four engine units to produce 100 and 200 hp respectively. Marinisation would have to be considered for particular installations.

Yanmar Diesel's 20 and 45 hp outboard motor units could be made available.

3.5.2

For powers around 100 hp, the water cooled NSU KKM 612 (113.5 hp) could be available in small quantities but only as a petrol burning, standard car engine. The 110 hp T Kogyo 10A is a similar unit but would only be available in certain territories defined by the licence, and then only by special arrangement with the manufacturers and the licensors.

Both these engines would need modification and marinisation for hovercraft use and would need to be adapted for burning fuels other than petrol.

3.5.3

In the 150 to 200 hp range, Curtiss-Wright have developed various twin rotor, water cooled prototypes which have been tried in automotive, marine propulsion and generating applications. Some of these units are able to burn less volatile fuels than petrol; they are exceptionally light. However, there is no immediate prospect of production engines being available.

3.5.4

For powers from 250 to 350 hp, Daimler-Benz are working on three and four rotor versions of their type M 950 liquid cooled automotive units delivering 280 and 350 hp DIN respectively. These are unlikely to be available in the immediate future, though two units co possibly be made available for special tests in Germany. These engines would have to be adapted for burning fuels other than petrol, for example by using the Plessey ultrasonic ato They would probably also require adaptation of the rear end and marinisation.

The Curtiss-Wright twin rotor, air cooled RC2-90-Y2 which burns JP5 is rated at 310 and has an exceptionally good power/weight ratio but, like their other engines mentioned ab is not in production.

3.5.5

No Wankel engines are available yet for higher powers, though Rolls-Royce work on a compression-ignition unit is aimed at about 1,000 hp. Other possibilities include multiple engine arrangements of the Daimler-Benz or Curtiss-Wright units, should they become available. A four rotor version of the RC2-90-Y2 air cooled helicopter engine would also be attractive if Curtiss-Wright could be persuaded to develop it.