SECTION 6

CAPABILITY FOR ADAPTATION TO FUELS OTHER THAN PETROL

6.1 USE OF KEROSENE TYPE FUELS, SPARK IGNITED

6.2 COMPRESSION-IGNITION ENGINES

6.3 TRUE MULTI-FUEL CAPABILITY

6.0 INTRODUCTION

All the Wankel engines now in production operate on petrol. For this type of engine to be used on passenger carrying hovercraft it will have to be able to burn fuels having a higher flash point than petrol. Adaptation to burn a single fuel such as kerosene would satisfy the civil requirement but a multi-fuel capability is desirable for military use. The combustion characteristics of the Wankel engine appear to be favourable to such developments. It has proved possible, in the work at Curtiss-Wright and elsewhere, to run engines successfully on kerosene and diesel type fuels by using spark ignition in combination with fuel injection or ultrasonic atomisation systems. Wankel engine designs using compression-ignition are being developed at Rolls-Royce and elsewhere. The choice of engine type and fuel system for eventual multi-fuel use will depend on the range of fuels contemplated.

Work in hand and results so far are discussed under the following heads:-

1. Use of a kerosene or diesel type fuel, spark ignited.
2. Compression-ignition engines.
3. True multi-fuel capability.

6.1 USE OF KEROSENE TYPE FUELS, SPARK IGNITED

To use less volatile fuels than petrol it is necessary to ensure complete atomisation and adequate vaporisation of the fuel.

6.1.1

This can be effected by heat. Either the engine is started on a volatile fuel, e.g. petrol, and when warm and running smoothly is switched to, say, paraffin, either via a separate carburettor or on different jets, or alternatively suitable preheaters can be incorporated in the induction system.

No developments along these lines for Wankel engines are known to Hoverprojects.

6.1.2

The preferred method being tried on rotary engines is by fuel injection. The only work definitely known is by F. Krupp GmbH, Plessey, and by Curtiss-Wright. The latter published the results obtained (shown in Table 6.1), with an experimental single rotor, 90 cu.in. displacement, engine running on JP5 fuel.

Twin spark plugs, slightly inclined towards each other, were used for these tests. Further tests with both plugs in operation and with only one plug at a time have also been carried out but the results are not available.

TABLE 6.1

rev./min.	bhp	Specific Fuel Consumption lb/bhp hr		
		Single injector Standard rotor	Twin injectors Standard rotor	Single injector Modified rotor
3000	60	0.59	0.49	0.515
4000	90	0.60	0.495	0.505
5000	120	0.63	0.50	0.505
6000	145	0.68	0.54	0.535

Curtiss-Wright used high pressure injection into the combustion chamber, with spark ignition, and one of their prototypes ran successfully on Diesel No.2, JP4 and JP5 fuels. An attempt to extend this multi-fuel capability was made with the assistance of Rolls-Royce, under a contract from the then F.V.R.D.E., the results of which should be available from Ministry sources.

The research department of Friedrich Krupps GmbH wrote on the 8th September, 197 (Hoverprojects' translation), "The aim of this (our) development is to produce a multi-fuel engine, the advantages of which ... are its modest space requirements and the possibility of lightweight construction.

"To achieve this it is necessary to discard compression-ignition in favour of spark ignition and introduce a qualitative performance control in the form of fuel injection similar to the injection systems fitted to diesel engines."

6.1.3

The ultrasonic atomiser which is being developed in the U.K. and elsewhere offers a promising alternative to fuel injection*. In the U.K., Simms Group Research and Development Ltd. and Plessey have done work on rotary engines and some basic work has been done at Cranfield Institute of Technology and Imperial College. Work in the same field, but not on rotary engines, is being carried out in the U.S.A. by the American Petroleum Institute and also, it is believed, in the U.S.S.R.

The work by Simms was inconclusive and has been discontinued but the results are described in the following summary which they provided.

"This report covers test work carried out on a Fichtel & Sachs KM 48 rotary engine to investigate the possibility of developing a new fuel system incorporating an ultrasonic atomiser

* Morse, T. – Ultrasonics can help clean up those exhaust fumes – The Engineer, 5/3/1970.

"The work was carried out in two parts:

1. *Atomiser replacing carburettor.*

   The atomiser was tried both upstream and downstream of the throttle. In each case better specific fuel consumption figures were obtained except in the region of 2,400 rev./min. where an improvement was only apparent above 90 lb/in.^{2} bmep with the atomiser upstream. At higher output speeds the specific fuel consumption was improved by up to 13%.

2. *Direct injection into the combustion chamber.*

   Tests with this configuration were not easy to carry out owing to the sensitivity of the engine to fuel setting.

"The best layout for this system included an air bleed into the fuel supply close to the atomiser. This prevented an air lock building up in the supply line but it also showed that during cranking fuel tended to be blown out through the bleed whereas, when running, air was always being drawn in. This meant that the engine had to be started on the carburettor.

"Comparison of the consumption figures obtained with this layout in relation to those obtained with the carburettor showed considerable deterioration. For example, at 4,000 rev./min. for slightly less power the consumption was doubled. The most likely cause of this discrepancy is that a large proportion of the atomised fuel tends to form a liquid film on the rotor and the rotor casing. With the carburettor the fuel travels through a long heated port and has plenty of time to vaporise by the time it reaches the combustion chamber and is in a much better condition for burning."

For a fuller understanding of this last comment it should be borne in mind that the rotor of the Fichtel & Sachs engine is charge cooled and that, in consequence, the charge has plenty of opportunity to pick up heat on its rather tortuous way through the engine.

It is understood that further work on direct injection would have involved expenditure on a new rotor housing to try the effect of altering the injector position and money for this was not approved. We understand that Simms would be prepared to reopen the investigation on a larger engine if financial support were forthcoming.

It would seem that only Plessey Ltd. have produced a more advanced prototype unit which has given satisfactory results on a number of piston engines. Development work is still in progress with the small Fichtel & Sachs rotary engine. The work is a private venture and no more information is available.

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6.2 COMPRESSION-IGNITION ENGINES

For military applications compression-ignition reciprocating piston engines have been developed which have multi fuel capability. It is probable that the same would apply to compression-ignition Wankel engines, when they are available. No such engines are in produc-tion as yet, but development work is being carried out by Wankel GmbH, the Crewe division of Rolls-Royce, and Yanmar Diesel.

6.2.1

In considering the relationship between spark and compression-ignition engines, where with the piston engine the designs are basically similar, a different approach is necessary for the Wankel engine. With the Wankel engine an attempt to increase the compression ratio results in a combustion chamber which at top dead centre is thin and has a very large surface for a given volume. This is detrimental to satisfactory combustion. Any attempt to improve combustion by providing a cavity in the rotor flank only exaggerates the poor surface/volume ratio of the remainder. Practical solutions which are being developed separately by Wankel and Rolls-Royce both employ pre-compression. In this way the geometrical limitations of providing sufficient compression in a single stage are avoided.

These points are illustrated in Figure 6.1 which is based on an illustration originally prepared by Ing. D. Eiermann, Wankel's Chief Technician. This shows various engine configu-tions, all of which have the same displacement.

(a) shows an overhead valve petrol engine of 9 to 1 compression ratio with the dom piston at top dead centre.

(b) represents a petrol burning Wankel engine having a compression ratio of 8.5 to 1. With the rotor in the t.d.c. position, 49% of the combustion chamber volume is in the depression in the rotor flank.

(c) shows a typical compression-ignition piston engine. The compression ratio is 19 to 1 and the spheroidal combustion chamber is in the piston crown.

(d) represents the familiar Wankel configuration with three sided rotor, as in (b), but designed for a compression ratio of 16 to 1. 18.9% of the volume of the comb-tion chamber in the t.d.c. position is in the depression in the rotor flank. The large, thin combustion chamber, with its large surface/volume ratio, which would make it extremely difficult to achieve satisfactory combustion in a compression-ignition engine, can be clearly seen.

(e) represents an entirely different Wankel engine which has a four sided rotor in a three lobed housing. This is run in conjunction with a pre-compressor consisting of a two sided rotor in a single lobe housing. In the t.d.c. position the depress in the rotor flank contains 50% of the volume of the combustion chamber, whic

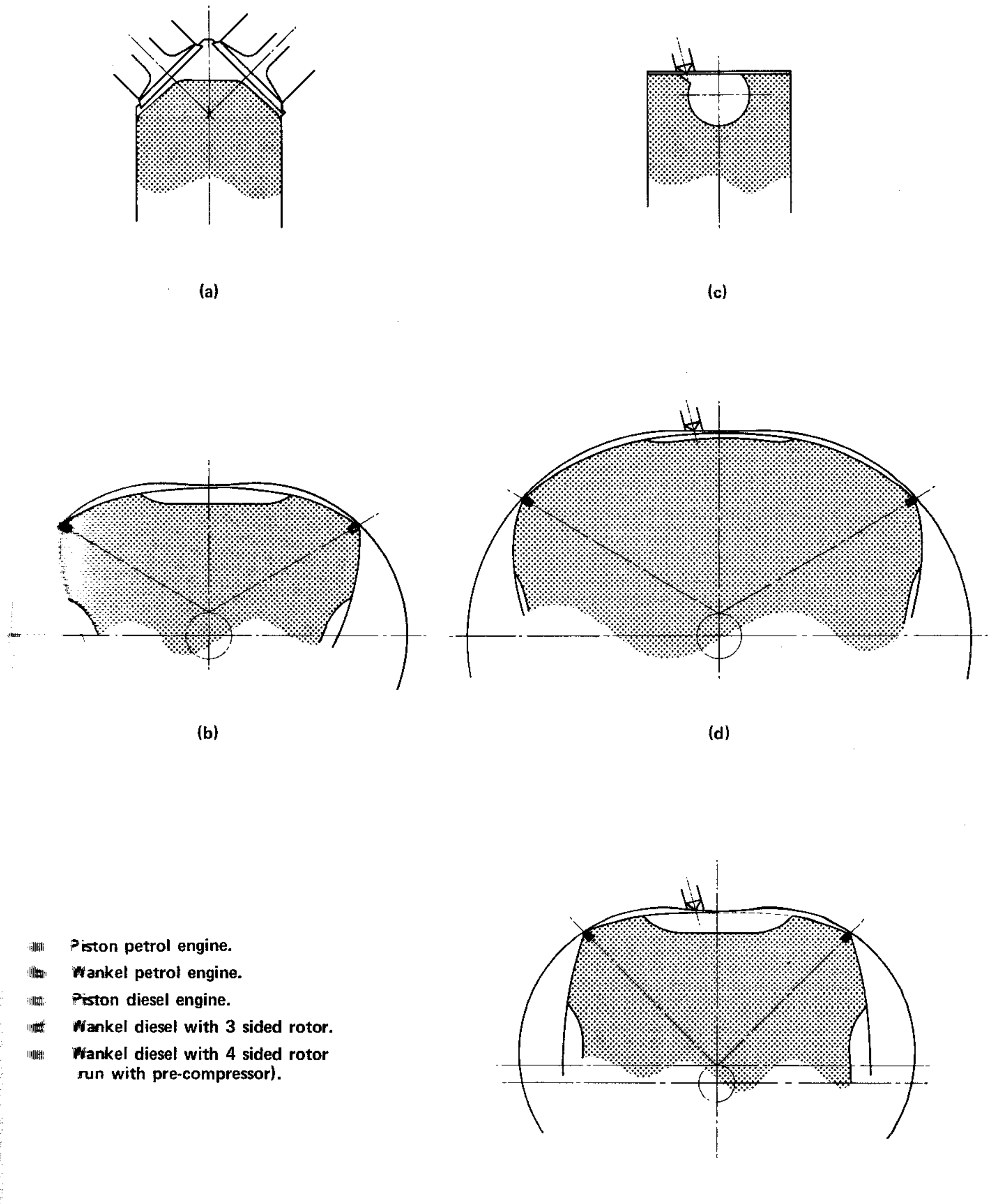

Fig.6.1 Various combustion chamber configurations of petrol and diesel engines, see Section 6.2.1

A prototype of this design, having a compression ratio of 16 to 1 is being made at th Wankel research establishment and is estimated to deliver 60 bhp at 6,000 rev./min. with a displacement of 720 cc. (In fact, the four sided rotor, three lobed housing configuration do not, of itself, facilitate the functioning of a sensible thermodynamic cycle, unless run with a pre-compressor, as it offers additional phases.)

The Crewe division of Rolls-Royce are using another configuration to achieve compression-ignition.* As described under 3.3.1, they are working with M.V.E.E. on a two stage engine, each stage consisting of the normal three sided rotor in a two lobed housing, the stages being connected by transfer ports. The only fuel mentioned in the information published to date is DE 2045 diesel fuel, which is injected direct into the combustion chamb However, the engine is intended for military purposes and powers up to 1,000 hp, and one aim is to develop it to burn a range of fuels.

6.2.2

Dr Felix Wankel is believed to be favourably disposed towards collaboration with a British company for the purpose of developing the compression-ignition RC engine. Some work in this field has been carried out by licensees in Germany. No progress has been repor on the conversion of the familiar three sided rotor, two lobed housing configuration into a compression-ignition cycle engine. It is understood that the results obtained support the vie that some form of two-staging, such as the development at Rolls-Royce and at Wankel's own research establishment, seems more likely to achieve success.

6.3 TRUE MULTI-FUEL CAPABILITY

6.3.1

By this is meant that engines may be run on any one of several conveniently available fuels without adjustment or alteration. The only known approach to the target so far achieved on the Wankel engine is the ability of a Curtiss-Wright engine to run on Diesel No.2, JP4 and JP5, mentioned above (6.1.2). However, attempts to achieve a multi-fuel capability are inherent in the development of the Rolls-Royce two stage, compression-ignition engine for military purposes (3.3.1), and in Plessey's work on the ultrasonic atomiser for use with spark ignition engines (3.4.3). In addition to the work at Curtiss-Wright, there are indications that the Wankel engine has potential in this direction, for example the ability of the automotive petrol engines to run satisfactorily on lower octane fuels than conventional piston engines of the same compression ratio. All current Wankel automotive engines run on regular grade petrol.

* Feller, F. – The 2-stage rotary engine – a new concept in diesel power.

Whether a multi-fuel capability is first achieved using compression-ignition or spark ignition with either 'solid' fuel injection or ultrasonic atomisation will presumably depend on where development effort is exerted and the range of fuels contemplated. Whatever fuel system is used, it will have to achieve satisfactory spray or vaporisation characteristics and to handle fuels such as wide cut gasoline, having virtually no lubricating effects.

6.3.2

An intermediate stage would be to:-

(i) Develop an engine to the point where it can burn several fuels provided minor changes are made when changing over from one fuel to another, for example, injector nozzles or ignition timing settings.

(ii) Carry development further so that a somewhat limited range of fuels can be used without adjustment, but adjustment is needed to accept another fuel outside this range.

It may be necessary to use a starting aid for cold starting on certain fuels or when the ambient temperature is exceptionally low.